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RELATIONS BETWEEN LOCAL MAGNETIC DISTURBANCES AND THE GENESIS OF PETROLEUM

BY

GEORGE F. BECKER

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ILLUSTRATION.

RELATIONS BETWEEN LOCAL MAGNETIC DISTURBANCES AND THE GENESIS OF PETROLEUM.

By George F. Becker.

VERY QUESTIONABLE ORIGIN OF THE HYDROCARBONS.

No question in geology is more obscure than that of the origin of the numerous natural hydrocarbons commonly classified as asphalt, ozokerite, petroleum, and natural gas. Certain facts of occurrence and certain results of experiment are indeed established, but the interpretation to be placed upon them is so doubtful that the conclusion reached may almost be said to depend on predilection. A great number of the more important hydrocarbons found in petroleums can be produced artificially from organic substances, such as coal, wood, and fish oil, while identical or closely allied hydrocarbons result from the interaction of inorganic substances, such as cast iron and chlorhydric acid. In many places petroleum is closely associated with fossiliferous strata; but hydrocarbons likewise exist in meteorites and in volcanic gases; they are even expelled by heat from granite and basalt. The most orthodox opinion at the present day is that a part of the natural hydrocarbons is of organic origin and a part also of inorganic origin; but when it comes to estimating the relative importance of the two portions there is no approach to unanimity. Before making a suggestion, which in this connection appears to be of interest, it may be well to outline the arguments for the opposing views.

ARGUMENT FOR ORGANIC ORIGIN.

Mr. Clarke has given an excellent digest of the evidence of organic origin in his "Data of geochemistry." It will be still more briefly summarized here. That hydrocarbons are produced by the destructive distillation of either vegetable or animal matter has long been known. The manufacture of illuminating gas from coal exemplifies the process. In 1865 Warren and Storer[a] made paraffins, olefines,

[a] Mem. Am. Acad., 2d ser., vol. 9, 1865, p. 177.

and aromatic compounds in mixture (thus practically manufacturing petroleum) from saponified fish oil; and in 1888 Mr. Engler [a] formed similar compounds under pressure from unsaponified fish oil. Later [b] the same chemist obtained hydrocarbons by distillation from vegetable oils. All of these results have been abundantly confirmed by other experimenters.

Many observed associations also point to organic genesis. Marsh gas (fire damp, methane) is the most volatile member of the paraffin series. It is generated in swamps and in coal beds and forms the greater part of natural gas. Rotting seaweeds likewise emit it, and there is some reason to believe that salt water by delaying putrefaction is favorable to the formation of hydrocarbons; at any rate brine and petroleum are often associated. Some petroleums, especially those of California, contain nitrogen bases, which tends to show that the oil has been derived from animal matter. According to Mr. F. Hornung,[c] the hydrocarbons of the Zechstein formation in the Harz region are derived from fish remains. In his opinion the fish were killed by brines of salt lagoons and their fats saponified by salts of lime, magnesia, and ammonia. If so, Warren and Storer's experiments completely illustrate the process.

The association of petroleum with sedimentary strata is well known; in fact, oil is found in large quantities only in stratified rocks. In a word, as Mr. Clarke [d] says:

> Wherever sediments are laid down, inclosing either animal or vegetable matter, there bitumens may be produced. The presence of water, preferably salt, the exclusion of air, and the existence of an impervious protecting stratum of clay seem to be essential conditions toward rendering the transformation possible. Seaweeds, mollusks, crustaceans, fishes, and even microscopic organisms of many kinds may contribute material to the change. In some cases plants may predominate; in others animal remains; and the character of the hydrocarbons produced is likely to vary accordingly, just as petroleum varies in different fields.

Granting the organic origin of petroleum, its accumulation may be accounted for in some measure by flotation, since it is lighter than water; but capillary displacement by water appears from the studies of Mr. David T. Day to be much more efficient than buoyancy. The presence of organic hydrocarbons in massive rocks might be ascribed either to capillary infiltration or to the incorporation by massive rocks of strata carrying organic matter. Similarly it is possible that the evolution of hydrocarbons in volcanic gases depends upon the distillation of organic matter by volcanic heat, and the same explanation may be applied to the marsh gas which is brought to the

[a] Ber. Deutsch. chem. Gesell., vol. 21, 1888, p. 1816.
[b] Cong. internat. du pétrole, Paris, 1900, p. 20.
[c] Ber. Deutsch. geol. Gesell., vol. 57, 1905, p. 538.
[d] Data of geochemistry, 1908, p. 640.

surface by hot springs with or without boracic acid. Even the asphalt lake of Trinidad may owe its origin to distillation or eliquation.

ARGUMENT FOR INORGANIC ORIGIN.

Of the rival hypotheses, that which ascribes to oil an inorganic origin is the less fashionable, and for that reason I shall discuss it somewhat more fully, though without any attempt at exhaustive treatment. Very famous men of science, however, have adopted this explanation as the more probable, and of these observers the first, so far as I know, was Alexander von Humboldt.

On August 12, 1805, Humboldt and Gay-Lussac witnessed a great eruption of Vesuvius; and at times they found the prevailing smell wafted from the crater bituminous. Humboldt had also noted in literature three cases in which a pleasant smell (Wohlgeruch) attended eruptions. "I put these few observed facts together," he says, "because they help to confirm the close connection of all manifestation of volcanic activity, the connection of brine-naphtha wells with real volcanoes."[a] This was a very long shot, even though aimed by the eye of genius.

Much evidence in favor of Humboldt's view has accumulated during the past century, however, and I think it can now be shown that such hydrocarbons as are immediately associated with volcanic or intrusive phenomena have an inorganic origin. The relative economic importance of the organic and inorganic oils is another matter. So also is the chemical theory of the relations of inorganic oils to other minerals.

DIGRESSION ON THE ORIGIN OF AMMONIA.

Most intimately connected with the origin of hydrocarbons is the derivation of the ammoniacal compounds emanating from volcanoes. In ordinary experience the source of ammonia is organic, and it is impossible to pass a stable without being reminded that ammonia is one of the commonest products of decay. It was therefore very natural that the pioneers in the investigation of volcanoes, such as Bunsen, should have regarded the ammoniacal fumes and the incrustations of ammonium chloride so abundant at active vents as due to the action of hot lavas on organic matter; but a comparatively recent investigation by Mr. J. Stocklasa seems to demonstrate that the ammonia is of inorganic origin, as others had suspected from less complete evidence.

[a] Cosmos, vol. 4, p. 274. This volume appeared in 1858. Whether Humboldt had referred to the matter in any earlier publication I do not know. I assume that his opinion was formed at the date of his observation. L. von Buch noted the smell of volatilizing petroleum (Bergoehl) at Vesuvius nearly a year before Humboldt (Geog. Beob., vol. 2, 1809, p. 216), but did not draw any general inference.

Mr. Stocklasa[a] made chemical tests in the field during the progress of the eruption of Vesuvius in April, 1906, supplemented later by laboratory work. He found that the gases emitted always contained chlorhydric acid and ammonia; that the glowing lavas are shrouded in a veil of ammonium chloride vapor even far away from any vegetation; that lava still hot from the crater yields (when powdered and leached with water) notable quantities of ammonium chloride; that the yellowish smoke forming the " pine tree cloud " above the crater of Vesuvius consisted chiefly of ammonium compounds; and, finally, that from the more solid fresh lavas, especially the olivine bombs, ammonia may be expelled by heat alone.

Though eruptions break out at various points on the cone of Vesuvius, analogy justifies the belief that it has but a single conduit or neck through which the eruptions of many thousand years have reached the surface. Any fossiliferous strata through which the conduit may pass must have been baked out long ago and must have yielded up any products of distillation with which the sediments could part. It thus seems quite impossible that the immense ammoniacal product of this volcano can have an organic origin.

Mr. Stocklasa considers it probable that the origin of the ammonia is referable to nitrides, especially that of silicon, which is easily prepared, but not known as an actual mineral. A nitride of iron, however (now known as silvestrite), was found at Etna by Orazio Silvestri[b] in 1875.

Others had preceded Mr. Stocklasa in maintaining that the ammoniacal emanations of volcanoes are due to the presence of nitrides in the magmas; for example, Mr. Armand Gautier[c] and Mr. A. Brun.[d] The last obtained ammonium chloride by calcination from all lavas, acidic or basic, with which he experimented. His list included specimens from Krakatoa, Chimborazo, Bourbon Island, and Hecla, as well as a long suite from the Mediterranean. Mr. Brun also anticipated Mr. Stocklasa in asserting that the smoke of volcanoes is largely composed of chlorides.

Ammoniacal compounds appear to be almost or quite invariably present in volcanic emanations. They are also found, I believe, without exception in boric acid springs, or suffoni, and in many other thermal springs. If ammonia were only occasionally associated with volcanic phenomena and igneous rocks, its presence might be at-

[a] Ber. Deutsch. chem. Gesell., vol. 39, 1906, p. 3530.

[b] Pogg. Annalen, vol. 157, 1876, p. 165. Silvestri lays especial emphasis on the formation of ammonium chloride within the great crater of Etna where, he says, an organic origin for this substance is not to be thought of.

[c] Bull. Soc. chim., 3d ser., vol. 29, 1903, p. 191.

[d] Arch. sci. phys. et nat., vol. 19, 1905, pp. 439, 589.

tributed to adventitious organic matter. The evidence of the inorganic origin of the ammonia emitted by volcanoes is cumulative but conclusive.[a]

ASSOCIATIONS OF HYDROCARBONS.

After Humboldt's qualitative detection of hydrocarbons at Vesuvius their study seems to have been neglected for a long time. Bunsen [b] indeed looked for hydrocarbons at Hecla, but in vain. In 1856 Ch. Sainte-Claire Deville found them on the flank of Etna near Aci Reale as gaseous emanations.[c] In the main crater he detected no hydrocarbons, a fact which he attributed to combustion in the volcanic hearth. Fouqué first actually collected hydrogen and marsh gas from an incandescent crater, that of Santorin.[d] He considered the circumstances at this locality peculiar in that the atmosphere had uncommonly little access to the gases on their way to the vent. As a rule, in his opinion, a volcanic cone is so porous and so charged with air that combustible gases are consumed in the heart of the mountain. He thus agrees with Deville, and Mr. Stocklasa holds a similar opinion. From this point of view an ordinary volcano would resemble a Bunsen burner in which the flame has "struck back." Since Deville's first investigations hydrocarbons have been found at Vesuvius, Etna, Santorin, Terceira Island (in the Azores), and at Pélee by Fouqué, Gorceix, Silvestri, and Moissan.[e] Hydrocarbons have also been detected spectroscopically in the gases of Kilauea by Jannssen [f] and by Libbey.[g] Mr. Stocklasa, whose investigations on the ammoniacal products of Vesuvius were referred to above, promised a special paper on the hydrocarbons, but this I have not succeeded in finding. He states, however, that the lavas contain hydrocarbons, and he attributes to their combustion the steam and carbon dioxide of the vapors.[h] In short, it seems only needful to look for hydrocarbons under favorable conditions at volcanic vents to find them in the gases.

Ch. Sainte-Claire Deville was a pioneer in the examination of the gases liberated by heat from massive rocks. "Obsidians," he says, "are well known to be due to the rapid cooling of lavas, especially those rich in silica. Now, the greater part of the obsidians still retain water, sodium chloride, and bituminous or ammoniacal substances,

[a] Mr. Clarke, remarks Stocklasa, "has clearly shown that the nitrogen of lava is an original constituent and not of organic origin." Data of geochemistry, p. 222.

[b] Annales chim. phys., 3d ser., vol. 38, 1853, p. 215.

[c] Compt. Rend., Paris, vol. 43, 1856, p. 359.

[d] Santorin et ses éruptions, 1879, p. 225.

[e] Mr. F. C. Lincoln (Econ. Geology, vol. 2, 1907, p. 258) gives 50 analyses of emanations with references.

[f] Compt. Rend., Paris, vol. 97, 1883, p. 602.

[g] Am. Jour. Sci., 3d ser., vol. 47, 1894, p. 371.

[h] Chem. Zeitung, 1906, p. 740.

and if they are rapidly heated to a temperature well below the melting point, they swell up, becoming extremely porous, passing, in short, into the condition of pumice."[a] Mr. Brun has repeated and extended this investigation.[b] From a Lipari obsidian he dissolved out with ether a vaseline-like grease, and by the same method he obtained an oil from Vesuvian ash of 1904 which floated on water. He found hydrocarbons abundant in Stromboli lavas of 1901 and in Santorin andesite of 1866. Even an obsidian from Plomb du Cantal (Auvergne), the date of which is of course unknown, yielded hydrocarbons copiously. In later investigations Mr. Brun[c] found hydrocarbons in the ash or cinder of two volcanoes in the Canary Islands and of four volcanoes on the Island of Java. The portion of Java north of the volcanic belt contains numerous pools of petroleum, and Mr. Brun says he is forced to admit that this petroleum is of eruptive origin, but he does not give his reasons for this conclusion. Silvestri actually found bubble-like pockets in the lava of Etna containing solid paraffins and liquid oil.[d]

It is difficult to draw the line between active volcanism and solfatarism. Most of the cases in which hydrocarbons can be shown to escape in volcanic districts are to be classed as solfataric, for incandescent vents are hard to approach, and the gases if present would inflame. The bitumens of the Auvergne are probably solfataric. The association of lava and bitumen in that region is very close, and the basaltic tuffs, or peperites, which in many cases form volcanic necks, are heavily impregnated with hydrocarbons. The most famous of these rocks is the bituminous tuff of Puy de la Poix. It is noteworthy that the volcanoes of the Auvergne rest on a great granite massive, and in this rock actual veins of bitumen occur.[e] Solfataric, too, are the occurrences of bitumens at quicksilver deposits, for hot water and gases pour through some of them, while the extreme similarity of most of these ore deposits indicates community of origin. In every quicksilver-producing district in California bitumens are present, usually and perhaps always members of the paraffin series. They are found with the ore embedded in hydrous silica. Bitumens also accompany the quicksilver ores in Texas, in Rhenish Bavaria, at Idria, at Monte Amiata, and at Almaden.[f] There is an especial and unexplained affinity between bitumen and cinnabar,[g] an ore which has undoubtedly been brought to the surface in solution from great depths.

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[a] Sur les émanations volcaniques, Paris, 1857, p. 14.

[b] Arch. sci. phys. et nat., 4th ser., vol. 19, 1905, p. 589.

[c] Bib. univ. arch. des sciences phys., vol. 27, 1909, p. 113.

[d] Gazz. chim. ital., vol. 7, 1877, p. 1.

[e] See De L'Apparent, Traité de géologic, 5th ed., 1906, pp. 541, 1786; also Geikie, Textbook, p. 357.

[f] Quicksilver: Mineral Resources U. S. for 1892, U. S. Geol. Survey, 1893.

[g] Paraffins partially precipitate mercuric sulphide from its solutions in alkaline sulphides.

The diamonds of South Africa occur in volcanic necks, and it is now generally acknowledged that the gems are native to the subsilicic, peridotitic rock known as kimberlite.[a] In this rock Moissan found carbonado and graphite, which was more abundant than diamond.[b] Sir Henry Roscoe also examined the kimberlite. A quantity of it was powdered and digested with ether. "On filtering and allowing the ether to evaporate," he says, "a small quantity of a crystalline, strongly aromatic body was obtained. This substance was very volatile, burned easily with a smoky flame, and melted at about 50° C."[c] There can be no doubt, I take it, that these necks extend downward to a depth of many miles.

The famous Tuscan boracic "suffoni," or fumaroles, emit gases. They were examined as early as 1858 by Deville and Le Blanc,[d] and without exception they were found to contain hydrocarbons. They have repeatedly been analyzed since that time, with a similar result.[e] All the suffoni appear to carry ammoniacal compounds also, while boric acid is characteristically of volcanic origin. If any line can be drawn between suffoni and the boric, ammoniacal asphalt lake of Trinidad I do not know how to do it.

Massive rocks at a distance from active volcanoes or distinctly solfataric phenomena contain hydrocarbons. At some points masses of solid or liquid oils exist in ancient massive rocks, but these may perhaps be derived from extraneous sources. Mr. W. A. Tilden[f] showed, however, that granite and gabbro, as well as basalt, when heated to redness, give off gases in volumes several times as great as that of the rock itself, methane being one of the educts. The granite developed about a twelfth of its own volume of marsh gas and gabbro an eighth. Mr. Armand Gautier[g] has also analyzed the gases driven off by a red heat from granite, granitoid porphyry, and ophite, getting about one volume of methane to seven of the rock. If the unit volume is taken as a cubic mile, these figures become impressive. In what form the hydrocarbon exists in the rock before heating is uncertain, but it can hardly be merely adsorbed (or condensed on surfaces), for pulverization scarcely reduces the quantity. This behavior seems inconsistent with the idea that the presence of methane is due to the diffusion of a gas of organic origin or to the infiltration of exotic oils.

For the sake of completeness, the presence of methane in thermal springs not referable with certainty to volcanic action may be men-

[a] I could not find the least evidence of change even in the sharpest splinters of shale embedded in the lava. Science, vol. 6, 1897, p. 664.
[b] Compt. Rend., Paris, vol. 116, 1893, p. 292.
[c] Proc. Manchester Lit. and Phil. Soc., vol. 24, 1885, p. 8.
[d] Compt. Rend., Paris, vol. 47, 1858, p. 317.
[e] For example, by Mr. R. Nasini (Gazz. chim. ital., vol. 28, 1898, p. 100).
[f] Chem. News, vol. 75, 1897, p. 169.
[g] Annales des mines, 10th ser., vol. 9, 1906, p. 316.

tioned. There is a growing belief that springs of high constant temperature and constant flow emanate from points below the level to which stratified rocks usually extend, and that the water is either "juvenile" (i. e., of recent formation) or magmatic. This opinion is founded on the impossibility of accounting for the composition of such springs as those of Bohemia on the hypothesis that the waters are vadose.[a] Mr. F. W. Clarke[b] has thrown new light on this subject by showing that all the sodium of the sea and the sedimentary strata might be supplied by a shell of igneous rock, enveloping the globe, with a thickness of half a mile at the very most. Supposing the relative areas of land and sea always to have been substantially the same as at the present day, and making any reasonable allowance for erosion, the mean thickness of stratified rocks in continental areas can be only a fraction of a mile. Mechanically, also, it is most difficult to conceive how the purely superficial action of erosion and decomposition could ever result in burying the primeval rocks under detritus to an average depth of many thousand feet. Hence it would seem that typical hot springs must come from beneath the sediments. Now great numbers of hot springs in France, Germany, Austria, and elsewhere carry methane. This gas seems too common in such springs to be attributed to fortuitous association with organic deposits, and it is reasonable to regard it as magmatic.

CONCLUSION, THAT HYDROCARBONS ACCOMPANYING IGNEOUS ROCKS ARE INORGANIC.

Of all the associations of hydrocarbons briefly enumerated above, perhaps not a single one is incapable of explanation on the hypothesis that the hydrocarbons are of organic origin. It is possible to conceive that in exceptional circumstances an obsidian should have been kept melted within a few thousand feet of the earth's surface in an atmosphere of organic hydrocarbons until it had occluded as much of such material as can now be expelled from it by heat. So, too, it can be imagined that at the Puy de la Poix a fissure extends through the granite to some distant accumulation of organic bitumen and that this has merely been distilled into the peperites. So long as only a few isolated cases of the presence of hydrocarbons in volcanic educts and massive rocks were known, such explanations might suffice. They no longer seem sufficient or plausible. The cases of association are so numerous and their character is so diverse as to break down the hypothesis of merely fortuitous collocation. The evidence is indeed mainly cumulative; but it has so accumulated and is so consistent as to leave only a negligible probability that the con-

[a] Vadose waters are those which have infiltrated from the earth's surface.
[b] Data of geochemistry, p. 29.

nection is not genetic. I see no logical way of avoiding the conclusion that much the greater part of the hydrocarbons associated with eruptions or occluded in massive rocks has an inorganic origin.

Evidence similar to that here adduced has carried conviction to the minds of some of the highest geological authorities of the day. Sir Archibald Geikie in his text-book seems to make only a single reference to the hypothesis of the organic origin of the hydrocarbons attending volcanic phenomena. From the association of hydrocarbons with igneous rocks he says:[a] "The opinion has been formed that these emanations do not proceed, as has generally been supposed, from the decomposition of coal or other sedimentary material of carbonaceous composition and vegetable origin, but rather point to the existence of vast quantities of carbon combined in the interior of the earth with such metals as iron and manganese." In another passage he remarks:[b] "The association of mineral oil, marsh gas, and other hydrocarbons, and of carbonic acid in old volcanic districts, may thus point to the continuous decomposition of such carbides by access of water."

Mr. de Lapparent is even more decided in the expression of his views. "In short, there is no doubt," he says,[c] "that the lavas of Santorin in a state of pasty fusion were accompanied to within 100 meters of their point of emergence by combustible gases originally imprisoned in their mass." So, again:[d] "It seems, then, that the basaltic emissions of the Miocene, forming a prelude to the great volcanic activity of the Auvergne, were accompanied by abundant outflows of hydrocarbons."

More than thirty years ago Mr. Tschermak[e] gave his assent to the hypothesis that volcanic gases are derived from the interior of the earth, likening eruptions to the tremendous outbursts which cause sunspots.

Mr. Eduard Suess[f] has happily characterized as *juvenile* the newly formed products of reactions which occur in volcanoes or solfataras and which accompany allied manifestations of energy. He thus classifies the carbon dioxide and the aqueous vapor of volcanoes as well as the formic acid detected by Fouqué at Santorin. In his opinion the carbon and the hydrogen are oxidized at eruption and, though he does not make the statement, it may be inferred that he supposes these elements to have been combined as hydrocarbons. Mr. Suess disclaims originality for the theory of juvenility, assigning the credit to the group of French scientists whose work has been referred to

[a] Text-book of geology, 4th ed., 1903, p. 86.
[b] Idem, p. 270; see also p. 185.
[c] Traité de géologie, 5th ed., 1906, p. 448.
[d] Idem, p. 1786.
[e] Sitzungsb. Akad. Wien, vol. 75, 1877, p. 151.
[f] Ueber heisse Quellen: Verhandl. Gesell. deutsch. Naturf. und Aerzte. 1902, p. 133.

above; but he gives it his hearty adhesion, reinforced by observations of his own.

This list of authorities might be extended, but that seems superfluous since it could not be improved.

IMPORTANCE OF INORGANIC HYDROCARBONS.

No direct means has yet been found of determining quantitatively the amount of hydrocarbons brought to the surface by eruptions. Much of it must burn while some escapes to make "a pleasant smell." It would seem to me that careful quantitative work on obsidians would be most likely to furnish data for estimating the percentage content of the magmas. If any considerable part of the water and carbon dioxide of eruptions is due to the combustion of hydrocarbons, as Sainte-Claire Deville, Fouqué, Messrs. Suess, Stocklasa, and others have inferred, the total must, of course, be enormous. By examining the accounts of experiments it appears that ammonium chloride and hydrocarbons are generally referred to in similar terms, as if at least the order of magnitude of the two kinds of emanation were the same. In fact I am unable to guess from the published investigations whether ammoniacal compounds or hydrocarbons predominate in obsidians and recent lavas. Now, according to Mr. Stocklasa, a large part of the emissions of Vesuvius consists of ammoniacal compounds. When the scale of a Vesuvian eruption is borne in mind, it appears that the total quantity of these salts expelled is immense. Thus even if the quantity of hydrocarbons attending eruption were only a very moderate fraction of the ammoniacal output, volcanism must be competent to yield exceedingly valuable quantities of hydrocarbons.[a]

Even if petroleum of organic origin were exceptional, the distribution of oil might resemble its actual disposition. An accumulation of inorganic oil within reach of vadose water would be driven toward the surface by capillary displacement and buoyancy. If the surrounding rocks were intersected in all directions by cracks, the oil would be expelled at least in part through springs. Only an impermeable sheet of rock could prevent this expulsion, and the only rock found in sheets impervious to liquids is moist clay. Hence it is to be expected that inorganic oil when it occurs in considerable quantity should impregnate the rocks underlying clays. But such rocks are usually stratified and frequently fossiliferous. Oils of organic origin would behave in the same way and would also accumulate, if at all, beneath clay. Hence the well-known fact that petroleum is found in these circumstances proves nothing whatever as to its origin.

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[a] Mr. Brun asserts that the Javanese petroleum is of eruptive origin, but does not offer detailed evidence that it is so. Java oil is not unlike that of Pennsylvania.

From another point of view also the argument that the genesis of petroleum is organic because oil is associated with fossils may be pushed too far. In swamps the accumulation of vegetable matter is enormous, as everyone knows. In the open sea conditions are very different. The Atlantic coast of Virginia is one long beach plentifully strewn with shells, but not one in thousands of these contains a shellfish, and the seaweed driven up by a storm disappears with wonderful rapidity. It is safe to say that an acre of the Dismal Swamp carries more organic matter than 10,000 acres of Virginia beach. Even in tropical seas, where life is most abundant, dead animals and plants are rarely to be found. For the most part, living things there are consumed *while* they die. An ooze is derived from organisms which have perished at the surface, and their remains must in many cases take weeks to reach the bottom. What fatty tissue surface scavengers and the deep-sea fauna do not assimilate must be almost completely decomposed by bacteria during the long journey to the grave and the slow process of burial beneath the remains of survivors.[a] The simplest and best proof that there are no great accumulations of dead organic matter in the sea is that the ocean is not a stinking pool, but a great reservoir of purity. Hence, where notable quantities of oil are found in sandstones and limestones associated with marine fossils, as is commonly the case, there is ground for suspecting that the oil is at least exotic, if not inorganic. In shales, on the other hand, the presumption is the other way. Many mud flats are full of dead organisms, a part of which may in time be hermetically sealed by argillaceous matter; moreover, when a small amount of induration has taken place without desiccation the mass becomes impervious to allothigenetic oil.

It now appears certain that bituminous compounds are derived in part from organic matter and in part from azoic magmas. There is satisfactory evidence also that neither portion is economically insignificant.

THEORIES OF INORGANIC GENESIS ALL UNSATISFACTORY.

In the foregoing pages the attempt has been made to set forth the facts with as little reference to hypotheses as practicable. Study of the associations of the hydrocarbons leads irresistibly to the conclusion that notable quantities of inorganic hydrocarbons exist in nature, but does not indicate whether or no they are juvenile, or if juvenile how hydrogen and carbon came to unite. The present state of knowledge and speculation on this subject can be briefly set forth.

[a] It is reasonable to suppose that the fecundity of the abysmal fauna keeps pace with the food supply which reaches the bottom; "broth," as William B. Carpenter called it. For a lucid discussion, see Mr. A. Agassiz's Three Cruises of the Blake, Mus. Comp. Zool. Bull. 14, 1888.

Mr. N. V. Sokoloff [a] has maintained that the bitumens are of cosmic origin, that they were inclosed in the mass of the earth and have since been emitted. In short, he supposes the hydrocarbons as such to be magmatic and to exist within the earth in solution, solid or gaseous. Various other writers either take this view or do not expressly dissent from it. More widely held is the hypothesis that the carbon exists within the earth in the form of carbides of metallic bases. Most of those who adopt it appear also to suppose that the hydrogen of the hydrocarbons is derived from water, though this does not seem a necessary complement of the carbide theory.

Mendeléef [b] was the first to suggest that in nature hydrocarbons were made from carbides, viz, those of iron. Experimentally he relied for support on the well-known fact that artificial irons, cast or wrought, if dissolved in chlorhydric or sulphuric acids, develop hydrocarbons. He held that the earth had an iron nucleus similar in composition to siderolites and believed that water at high temperatures and pressures would react as follows:

$$3Fe_mC_n+4mH_2O=mFe_3O_4+C_{3n}H_{8m}.$$

That steam at high temperatures produces a coating of magnetic oxide on iron is well known, and it is most likely that the nascent hydrogen would unite to some extent with the combined carbon of hard irons; but Mendeléef does not seem to have demonstrated this. Moissan objected [c] to this theory because cementite (Fe_3C), the only well-known iron carbide, is not decomposed by pure water or by sea water at 150°. It is nearly certain, however, that there are several iron carbides, and Moissan does not appear to have tried steam at higher temperatures.

Even the existence of the natural, terrestrial carbides of iron demanded by Mendeléef's hypothesis has been questioned, but it will be shown a little later that this objection at least is not well taken.

That carbon irons digested with acids evolve hydrocarbons was first shown by J. L. Proust [d] more than a hundred years ago. He experimented both on cast iron and on iron sponge reduced at a relatively low temperature in glass. The most elaborate investigation is by Stanislas Cloëz.[e] He produced a long series of hydrocarbons from cast iron by solution in chlorhydric and sulphuric acids. From specular iron (which contains much manganese) he was also able to

[a] Bull. Soc. imp. nat. Moscou, new ser., vol. 3, 1890, p. 720.

[b] Ber. Deutsch. chem. Gesell., vol. 10, 1877, p. 229. This is a report of a meeting of the Russian Chemical Society, where Mendeléef made his views known in January, 1877. See also Mendeléef's Principles of Chemistry, vol. 1, 1905, p. 402.

[c] Traité de chimie, vol. 2, 1905, p. 374.

[d] Nicholson's Jour. Nat. Phil. Chem., etc., vol. 5, 1803, p. 100, quoting from Jour. de physique, ed. by de Lamétherie, vol. 56, 1802, p. 276.

[e] Compt. Rend., Paris, vol. 78, 1874, p. 1565; vol. 85, 1877, p. 1003; vol. 86, 1878, p. 1248.

evolve hydrocarbons by the action of water at a low red heat, and from ferromanganese by water at only 100°. Mendeléef, too, made from manganiferous pig iron, by the action of chlorhydric acid, a mixture of hydrocarbons indistinguishable from naphtha. Of course this is interesting and important, but native irons seem to contain the merest traces of manganese.

As is well known, Moissan [a] produced in the electric furnace and studied in some detail a long series of metallic carbides. The carbides of the metals of the alkalies and the alkaline earths when brought into contact with water yield acetylene which has not been found in petroleum. The carbide of aluminum gives methane and that of manganese equal volumes of methane and hydrogen, whereas the carbides of iron, nickel, and cobalt in water do not emit hydrocarbons at ordinary temperatures. Moissan [b] was led by this investigation to believe that carbides, other than those of iron, exist in the interior of the earth and that their decomposition by water yields a part of the petroleum. (The bituminous schists of Autun, on the other hand, he thought organic.)

This hypothesis has much to recommend it. That temperatures of well over 2,000° exist within the earth I think almost certain, because the temperature of the earth at its consolidation must have approximated to a condition of convective equilibrium. There seems no known reason why carbides besides those of iron might not have formed in the earth, especially those of aluminium and manganese. None have been found as yet, however. Possibly they may exist in a state of solid solution, and thus have escaped recognition. Until they are recognized, Moissan's theory is only plausible.

It is a mystery to me why Mendeléef and Moissan should have relied for the decomposition of their carbides on water alone. Volcanic eruptions are regularly accompanied by the emission of vast quantities of ammonium chloride and free chlorhydric acid. According to Mr. Suess, the amount of free chlorhydric acid is sometimes so great that volcanic rains seriously injure vegetation over wide areas. Again, ammonium chloride splits up into ammonia and free chlorhydric acid at a temperature approaching 350° under atmospheric pressure. Visible red heat begins near 500°, so that except in the cooler parts of a volcano none of the chlorhydric acid near the surface is neutralized by ammonia. Even in solution ammonium chloride may be partially dissociated, ammonia escaping and leaving a certain amount of free chlorhydric acid. Hence it would seem that volcanic waters would in most cases be acid and competent to evolve hydrocarbons from iron carbides.

[a] Traité de chimie, vol. 2, 1905, p. 259.
[b] Proc. Roy. Soc., London, vol. 60, 1896–97, p. 156.

Water, however, is not essential to the formation of hydrocarbons from carbides even as a solvent for acids. Mr. Brun[a] reports his results on this subject in the following terms:

The chemical reactions in volcanoes proceed without the cooperation of water; this the writer has confirmed anew from observations on Pico de Teyde and Timanfaya, in the Canaries. In discussing the formation of hydrocarbons (which are very common in volcanic ash) it is evident that the reactions between carbides and ammonium chloride, always present in abundance, must be taken into consideration. Salvadori[b] produced methylamine and acetylene from calcium carbide and ammonium chloride; and the writer observed during the same reaction the appearance of fluorescing hydrocarbons resembling crude petroleum. With iron carbide a paraffin-like substance was obtained, accompanied by gaseous hydrocarbons and free hydrogen. With aluminium carbide methane and hydrogen were evolved.

Artificial irons differ so considerably from the native metal that it seemed very desirable to test the action of dry ammonium chloride on Greenland iron. Mr. G. P. Merrill was good enough to supply me with a few grams from a specimen of an Ovifak iron, which is about as hard as the best tool steel, but very brittle, and which contains a large amount of combined carbon. The powdered metal was heated with pure ammonium chloride in an atmosphere of nitrogen. Of the educts a small portion condensed at zero degrees to a pasty grease, somewhat thicker than vaseline; a second portion, not condensible in ice water, was absorbed by bromine water, which was bleached as the absorption progressed. The gases escaping from the bromine water, after being freed from bromine, were passed over hot copper oxide and the carbon dioxide formed was caught as barium carbonate. Both saturated and unsaturated hydrocarbons were thus present in the educts. The gases which passed the bromine water will burn in air almost without luminosity and must consist mainly of hydrogen and methane. More of the carbon seems to be represented by the saturated volatile hydrocarbons than by the condensible oils or the bromine compounds, and the pasty grease therefore probably contains paraffin. The unsaturated hydrocarbons are perhaps due to the cracking of paraffins. I see no reason to doubt that cracking may occur in some solfataric oil deposits and that marked differences in the composition of oils from different pools may be thus accounted for. The combined carbon of the iron appears to be completely converted into hydrocarbons, for there is an approximate quantitative relation, and no graphite was detected in the residues from the metal. A brownish-gray, nonmagnetic powder remains behind which probably consists of iron nitrides.[c] Large quantities of nearly colorless crystals of ferrous chloride also form.

[a] Chem. Zeitung, vol. 32, 1908, p. 302.

[b] Gazz. chim. ital., vol. 32, 1902, p. 496.

[c] Either metallic iron or ferrous chloride heated in an atmosphere of ammonia yields silvestrite or other iron nitrides; Hintze, Handbuch der Mineralogie, vol. 1, 1898, p. 189.

These experiments were made for me by Mr. George Steiger, who will publish when completed such quantitative determinations as the amount of material available enables him to make. In the meantime it is established that solid, liquid, and gaseous hydrocarbons are copiously evolved by the action of dry ammonium chloride on native iron. There seems no reason to suppose that pressure would interfere with this evolution. It follows that the formation of hydrocarbons from inorganic substances may very probably take place at depths far greater than those to which vadose waters penetrate, far greater also than those at which stratified rocks are prevalent.

FACTS BEARING ON CARBIDE OF IRON THEORY.

That iron carbides exist in artificial iron is well and definitely known. Cementite, Fe_3C, was first prepared in a pure state by Moissan [a] in 1897, but seems to have been recognized as a distinct compound by Sir F. Abel in 1885. It is probable that several other carbides exist in smelted iron, but their study is attended by great difficulties.

Most modern metallographers accept, so far as its general features are concerned, Roozeboom's phase-rule diagram of iron constitution. As so represented, all uncombined carbon is graphite and the combined carbon is all combined in carbides. In respect to matters of detail, however, there are differences of opinion. It has been held by a number of metallographers that at ordinary temperatures the most stable mixture consists of ferrite (pure iron) and graphite; or, in other words, they believe that cementite tends to dissociate into graphitic carbon and iron. But two recent investigations by Mr. G. B. Upton [b] seem to disprove this view. He concludes that the most stable mixture consists of ferrite and Fe_2C accompanied by no graphite unless carbon is present in excess of the proportion represented by this carbide. In a higher metastable phase, as everyone acknowledges, cementite exists; but by very slow cooling Fe_3C is resolved, according to Mr. Upton, into Fe_2C and Fe. "Stead's brittleness" is referred to this change.

Among other confirmations of his views Mr. Upton cites the magnetic permeability of the soft, gray cast iron employed in the construction of electrical apparatus. He finds that this is only about half as great as it should be were the castings composed of graphite and magnetically "soft" ferrite.

In 1889 Mr. E. Weinschenck [c] discovered in the Magura meteorite a compound to which he gave the name cohenite. Its formula is

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[a] Traité de chimie, vol. 4, 1905, p. 392.

[b] Jour. Physical Chemistry, vol. 12, 1908, p. 507, and vol. 13, 1909, p. 388.

[c] Annalen Naturh. Hofmus. Wien, vol. 4, 1889, p. 94. I find some erroneous references in the literature to cohenite as FeC_3. The density of cohenite is 7.227. Moissan found the density of cementite 7.07.

$(Fe,Ni,CO)_3C$. This may be regarded as a cementite in which a part of the iron is replaced by nickel and cobalt, or cementite may be considered as a cohenite free from cobalt and nickel. Cohenite has since been identified in several meteorites and also in the terrestrial iron of Greenland at Ovifak and Niakornak, localities separated by about 100 miles.

The large amount of combined carbon in the Greenland iron has frequently been commented upon. Daubrée,[a] who found 3 per cent in one specimen from Ovifak, said: "The presence and abundance of carbon in these masses, combined carbon as well as that in a free state," is remarkable. J. Lawrence Smith[b] also found 2.34 per cent combined carbon in iron extracted in small particles from the basalt of Ovifak. His comment is: "The very large percentage of carbon in a state of combination in the iron of Ovifak, without traces of graphite, is a very interesting fact and demands a special chemical investigation." Although there was no graphite in the iron, Smith noted its presence in the basalt. In the Niakornak iron he found 1.74 per cent carbon, all combined. Mr. Carl Hintze[c] expresses his belief that the carbon of Smith's irons existed as cohenite.

In 1897 Emil Cohen[d] discovered that although Greenland irons disintegrate with great rapidity, the decomposition is not complete. In fact, unattacked metallic grains remain, and these can be practically freed from extraneous matter. Parcels of such grains, both from Ovifak and Niakornak, were analyzed for him by Mr. Sjöström and their composition found to correspond very satisfactorily to cohenite.[e]

This identification seems to me of great importance. Not only do the Greenland irons contain carbides, but cohenite must be stable at ordinary temperatures. The Greenland basalts unquestionably took decades to cool from the temperature of fusion, say 1,100° or 1,200°, to that of the atmosphere. No experimenter can hope ever to attain so gradual a cooling, and since the iron reached atmospheric temperatures it has had thousands of years to complete molecular readjustment. Cohen concluded that chalypite, or Fe_2C, does not exist in the Greenland irons. These facts, however, are not, to my thinking, necessarily inconsistent with Mr. Upton's conclusions. The nickel may make all the difference, and perhaps some of the good qualities of nickel steel are due to the stability of cohenite under conditions such that cementite would split up.

[a] Compt. Rend., Paris, vol. 74, 1872, p. 1542.
[b] Annales chim. phys., 5th ser., vol. 16, 1879, p. 452.
[c] Handbuch der Mineralogie, vol. 1, 1898, p. 190.
[d] Meteoritenkunde, heft 2, 1903, p. 226.
[e] Cohen remarks that these Greenland cohenites are identical with meteoric cohenite in their behavior to acid and neutral solutions as well as in composition.

For the present purpose the vital point is that all investigations of the Greenland terrestrial irons show the presence of iron carbides in abundance.

Mendeléef, in supporting his hypothesis, expressed his belief that the nucleus of the earth is composed of metallic iron, and it was from the action of water on this nucleus that he derived his hydrocarbons. The idea of an iron nucleus, long familiar, has grown in favor during the last half century. It is probable, indeed, that with such internal densities as are implied by the known mean density and surface density of the globe, stability would be impossible unless the intrinsic density of the nucleus were great. On the other hand, this nucleus, the barysphere, must lie far below the surface, several hundred miles assuredly, possibly a thousand; and it is improbable that surface influences of any kind are sensible at any such depths. Vadose water in particular is confined to an extremely superficial shell.

These considerations, however, involve only a very slight modification of the iron-carbide theory. If the earth, like meteorites, consists of metallic iron and rock, the rock must overlie the iron as slag does in a blast furnace, and it may be taken for granted that this slag contains "shot metal," that this rock contains entangled metallic particles which presented so much surface per unit volume as to prevent their sinking to the bottom of the viscid, lithoid magma. Such "particles," too, might have considerable dimensions and even weigh tons, since no provision was made in the world-building process for mobile slags and clean separation. It is thus rather to clouds of iron particles suspended in the lithoid shell of the globe than to an iron nucleus that advocates of the carbide of iron hypothesis of petroleum must appeal.

Native terrestrial iron or nickel iron has been found in many parts of the world, but nowhere in such abundance or in masses of such size as at Disco Island and the neighboring mainland of Greenland. Long before Nordenskiöld discovered this wonderful locality, Andrews had found specks of iron in the basalt of Antrim, Ireland. Irons supposed to be terrestrial have since been detected in every quarter of the globe, and though a meteoric origin is suspected for some of them, many are beyond question natives of this planet. At some points again a reduction by burning seams of coal or lignite is probable, but there are also many undoubted instances in which the metal is a component of a massive rock. Curiously enough, however, the native metals in which nickel predominates carry no appreciable amount of carbon. So far as carbides are concerned, therefore, awaruite, josephinite, and souesite must be ruled out, for all of them contain from 60 to 75 per cent of nickel.

In the United States native iron was first discovered by G. H. Cook[a] in New Jersey. "Native iron," he reported, "could be obtained from any of the specimens we had from the various ridges of trap in the red sandstone region of New Jersey." This iron evolved hydrogen with acids and precipitated copper from acid sulphate solution. In 1877 G. W. Hawes[b] found native iron embedded in magnetite in New Hampshire, and reported that he had also detected it in the fresh trap rocks of the Connecticut River.

In 1898 Mr. F. L. Ransome examined for me a series of several hundred thin sections of subsilicic rocks from various parts of the country, with a view to detecting metallic iron. The sections were uncovered, cleaned, and immersed in copper sulphate solution. It was found difficult to distinguish very minute particles of metallic copper from ferric oxide under the microscope, even in direct sunlight. After all doubtful cases had been rejected, only six sharply determinable occurrences from the United States remained. Of these four were olivine basalts from northern California, one a saxonite from Riddles, Oregon, and one a peridotite from Elliot County, Kentucky.[c] Had we been able to dispose of hand specimens by crushing them and extracting the magnetic particles, it is presumable that more localities would have been detected.

IRREGULAR COMPASS DECLINATION IN PETROLEUM FIELDS.

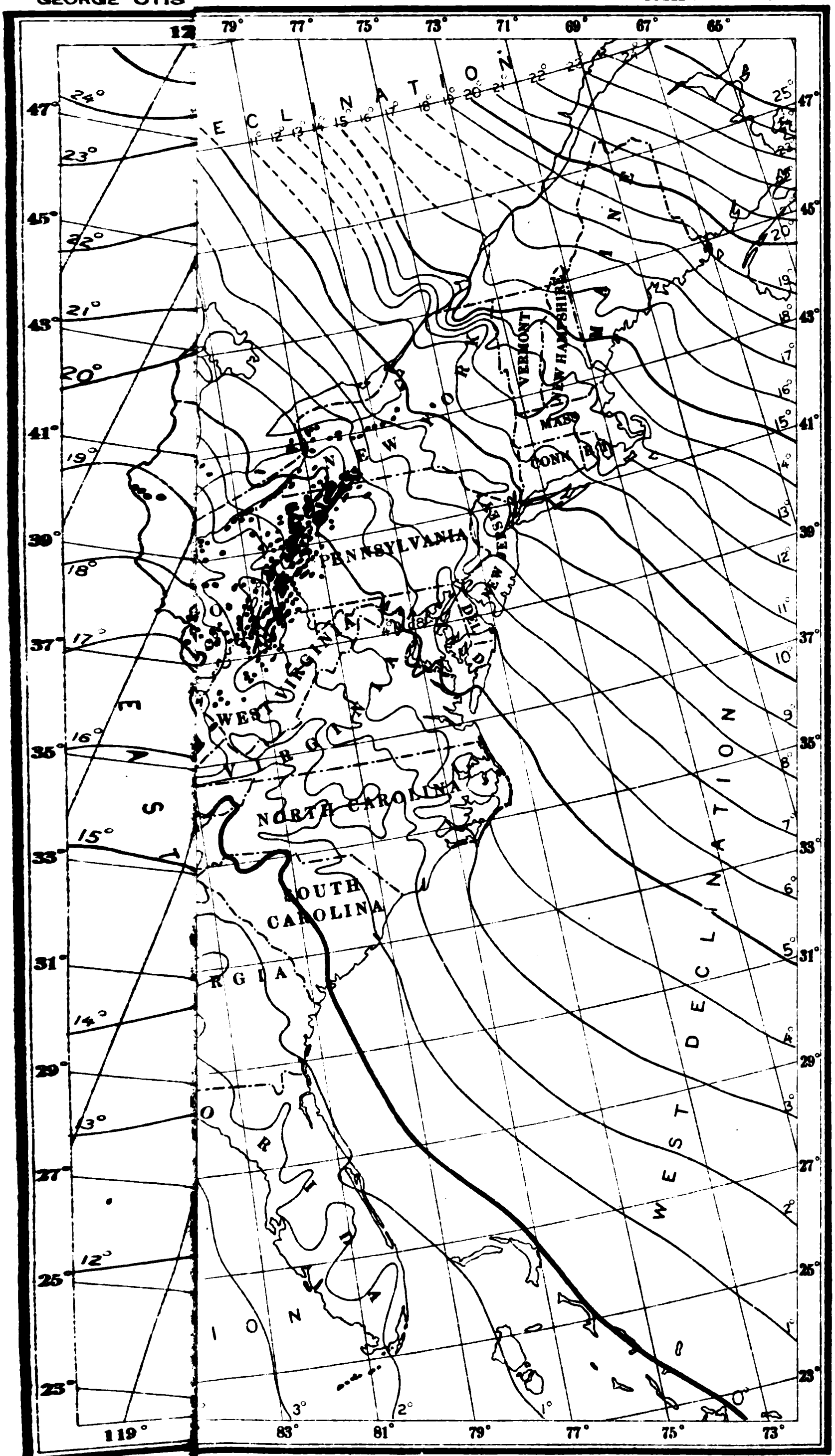
In the foregoing pages the condition of knowledge with reference to the origin of petroleum and other bituminous substances has been reviewed. The result is thoroughly unsatisfactory. Some oils are undoubtedly organic and some are beyond question inorganic. The evidence shows that neither variety can properly be regarded as unimportant. This review, however, does not elucidate the source of the principal deposits, the great petroleum pools. They may have been derived from carbonaceous matter of vegetable or animal origin, and they may have been derived from carbides of iron or other metals. It is also barely possible that the hydrocarbons exist as such in the mass of the earth.

In thinking over this situation it occurred to me to inquire whether any relation could be detected between the behavior of the compass needle and the distribution of hydrocarbons. Not very much could be expected from a comparison of these phenomena, for magnetite

[a] Ann. Rep. New Jersey Geol. Survey, 1874, p. 56.

[b] Am. Jour. Sci., 3d ser., vol. 13, 1877, p. 33.

[c] The basalts are (1) No. 369 Ps., H. W. Turner collection, Downieville quadrangle, 2.8 miles west by south from Mount Jackson; (2) No. 909 S. N., H. W. Turner collection, fragment from basaltic Tuscan tuff, Chico quadrangle, 4 miles a little east of south from Inskip; (3) No. 1789 C. R., J. S. Diller collection, 1.5 miles southwest of Lassen Peak; (4) No. 1168 M. S., J. S. Diller collection, 18 miles north of Mount Shasta, in Siskiyou County. The saxonite and peridotite have both been described by Mr. Diller.


DECLINATION
WEST DECLINATION
NEW YORK
VERMONT
NEW HAMPSHIRE
MAINE
MASS
CONN
R.I.
NEW JERSEY
PENNSYLVANIA
DEL
MD
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
SOUTH CAROLINA
FLORIDA
119°
83°
81°
79°
77°
75°
73°
71°
69°
67°
65°
47°
45°
43°
41°
39°
37°
35°
33°
31°
29°
27°
25°
23°

exerts an attraction on the needle whether this ore occurs in solid masses or is disseminated in massive rocks; and again, as was first shown by Messrs. Brunhes and David,[a] many if not all volcanic rocks possess polarity, so that repulsions are involved as well as attractions. Even if the iron carbide theory of genesis were known to be correct, and exclusively correct, no one would think of maintaining that all bodies of magnetite have a connection, however remote, with the occurrence of petroleum. Hence any indications of iron carbides and associated petroleum which the compass might be supposed to afford would be obscured by the local attraction of independent masses of magnetite. Earth currents are also to some extent local and thus produce irregularities in declination.

Nevertheless, on glancing at Mr. Bauer's map of the magnetic declination [b] in the United States for January 1, 1905, with this idea in mind, I saw that the irregularities of the curves of equal declination were strongly marked in the principal oil regions. When this map was compared with one prepared by Mr. David T. Day [c] showing in detail the known hydrocarbon deposits of the United States the coincidences recognized became more striking and other agreements became evident.

The chart accompanying this paper is merely a compilation from the two maps of Messrs. Bauer and Day. The red lines are the isogonal loci, and the black dots or blots represent deposits of hydrocarbons. The most marked agreement is found throughout the great Appalachian oil field, which is the area of greatest variation in declination. In California, also, strong deflections of the isogonal lines accompany the chain of hydrocarbon deposits. In the interior of the country the coincidences are less marked, but they are very noticeable, as may be seen by inspection of the map.

There are other systematic irregularities, wrinkles in the isogonic topography as I may call them, which can not be connected with oil. One such wrinkle runs down the Atlantic coast and contains the New Jersey native iron as well as known deposits of magnetite. Another lies near latitude 47° and is doubtless due to the great northern iron belt.

No detailed chart of the magnetic declination in the petroleum fields of the Caucasus has yet been prepared. Mr. Bauer informs me, however, that great magnetic disturbances exist in that region, so that relations not dissimilar to those in this country are probable.

[a] Compt. Rend., Paris, vol. 133, 1901, p. 155.

[b] A line of equal declination, also called an "isogonal line," is one along which the compass needle everywhere makes a particular angle with the geographical meridian. A magnetic meridian differs in toto from an isogonal line. The map referred to appeared in U. S. Coast and Geodetic Survey magnetic tables and magnetic charts for 1905, chart 1.

[c] Mr. Day was kind enough to place this map in manuscript at my disposal. It will appear in Mineral Resources U. S. for 1908, U. S. Geol. Survey, 1909.

Study of the map accompanying this paper justifies the statement that the coincidences between the occurrence of petroleum and local disturbances of the compass needle are too numerous to be attributable to mere accident or chance. There must therefore be a direct or an indirect historical connection between the two phenomena in the regions of coincidence.

CONCLUSIONS.

None of the hypotheses of petroleum genesis is proved by the relations shown on the map. These relations, however, are compatible with the supposition that the great oil deposits are generated from iron carbides either by or without the agency of water. Of these alternatives the latter is the more plausible.

What the map does prove is that petroleum is intimately associated with magnetic disturbances similar to those arising from the neighborhood of minerals possessing sensible magnetic attraction, i. e., iron, nickel, cobalt, or magnetite. Henceforth no geological theory of petroleum will be acceptable which does not explain this association.

No one doubts the vast industrial importance as well as the deep geological interest of the petroleum question. As time elapses it will grow more and more important, for the pinch of dwindling coal resources will probably affect children of those already born. In the interest both of the development and the conservation of our natural resources all the means at the command of science should be brought to bear on this mysterious subject. A geologist and a chemist each of the highest order should be coupled in the long and difficult investigations needed to elucidate the genesis of petroleum. The expense would be considerable but the economy would be enormous.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 402

THE UTILIZATION OF FUEL IN LOCOMOTIVE PRACTICE

BY

W. F. M. GOSS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1909

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ILLUSTRATIONS.

THE UTILIZATION OF FUEL IN LOCOMOTIVE PRACTICE.

By W. F. M. Goss.

INTRODUCTION.

The locomotives in service on the railroads of this country consume more than one-fifth of the total coal production of the United States. The amount is so large that any small saving that can be made effective in locomotive practice at once becomes an important factor in conserving the fuel supply of the nation. For this reason the United States Geological Survey has given attention to the special problems of combustion in locomotive boilers. It has approached this task from several different directions. The facts presented herewith constitute one series of results.

In the fall of 1906 the locomotive-testing laboratory of Purdue University, at Lafayette, Ind., entered on a series of tests, one purpose of which was to determine in precise terms the degree of efficiency with which a modern high-class American locomotive utilizes the heat energy of the fuel supplied to it. The general interest in the subject, the elaborate plans which had been formulated for conducting the work, and the substantial character of the support which had been pledged to maintain it justified the Geological Survey in aiding the investigation.[a] The cooperation of the Survey consisted in detailing experts to assist the regular staff of the laboratory in the chemical and calorific work of the tests. These experts, working under the general supervision of the director of the Purdue laboratory, became responsible for the sampling of smoke-box gases, of the fuel used, of the cinders caught in the front end, of the sparks discharged by the stack, and of the refuse caught in the ash pan. The gas analyses were made by them at the university laboratory. The analyses of all solid samples and the calorific tests of the fuels were made at the government fuel-testing plant at St. Louis. The representatives of the Survey were not concerned with other phases of the work.

[a] At the time mentioned the laboratory, aided by a grant from the Carnegie Institution, of Washington, D. C., was engaged in a general research concerning the value of superheated steam in locomotive service. See "Superheated steam in locomotive service," in press by the Carnegie Institution.

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straps inside and out and are sextuple riveted. The superheater is of the return-tube type and was built and installed in the summer of 1906.

The principal characteristics of the locomotive are as follows:

Type	4-4-0
Total weight .... pounds	109,000
Weight on four drivers .... do	61,000
Total wheel base .... feet	23
Cylinders:	
Diameter .... inches	16
Stroke .... do	24
Drivers, diameter outside of tire .... do	$69\frac{1}{4}$
Boiler:	
Type	Extended wagon top.
Length of fire box .... inches	$72\frac{1}{16}$
Width of fire box .... do	$34\frac{1}{4}$
Depth of fire box .... do	79
Number of 2-inch tubes	111
Number of 5-inch tubes	16
Length of tubes .... feet	$11\frac{1}{2}$
Heating surface in fire box .... square feet	126
Heating surface in tubes, water side .... do	897
Total water-heating surface, including water side of tubes .... square feet	1,023
Superheater:	
Type	Cole return tube.
Outside diameter of superheater tubes .... inches	$1\frac{1}{4}$
Number of loops	32
Average length of tube per loop .... feet	17.27
Total superheating surface based upon outside surface of tubes .... square feet	193
Total water and superheating surface, including water side of boiler tubes .... square feet	1,216

DISCUSSION OF TESTS.

PURPOSE.

The purpose of the tests was to determine the performance of the boiler and superheater of a normal locomotive while developing such rates of power as are common in locomotive service. The process involved a careful study of the various channels through which the heat energy of the fuel is absorbed or dissipated. The purpose of the work is best disclosed by Tables 1 to 13, which give the results of eighteen complete tests.

GENERAL CONDITIONS.

The general conditions under which the several tests were run are set forth in Table 1. The "laboratory designation" given in column 2 consists of three factors, the first of which represents the speed of the locomotive during the test, the second the position of the reverse

lever as expressed in terms of the notches forward of the center, and the third the boiler pressure. For example, test 1 (30–5–240) was made at a speed of 30 miles an hour, with the reverse lever in the fifth notch from the center, and under a boiler pressure of 240 pounds. Columns 1 and 2 are repeated in the succeeding tables.

The maximum power of the boiler may result from engine conditions involving a long cut-off and slow speed or a shorter cut-off and higher speed. The engine merely served during the tests to absorb the steam which the boiler generated and to supply, through the action of its exhaust, the draft necessary to stimulate the fire. This being the case, the conditions of speed and cut-off under which the engine of the locomotive was operated during the tests are not important to the present study.

The tests may be grouped into four series, for each of which the boiler pressure was the same. The first four tests were run under a boiler pressure of 240 pounds, the next five under a boiler pressure of 200 pounds, the next three under a boiler pressure of 160 pounds, and the remaining six under a boiler pressure of 120 pounds. The results of each series are presented in the order of the rate of combustion. Thus test 1 is the test of highest power and test 4 the test of lowest power in the 240-pound series.

COAL AND REFUSE.

Data concerning coal and refuse and certain other dependent factors are presented in Tables 2 and 3. Column 11 shows the total weight of coal fired for each test, and column 18 the coal fired per hour, which is a measure of the rate at which the coal was burned. For example, this rate for the first test was 1,975 pounds an hour and for the fourth test 1,210 pounds an hour.

The results represent work done with two grades of coal that will be designated as coal A and coal B. Both are of excellent quality. The greater part of the tests were run with coal A, which, for purposes of discussion, will be regarded as the standard for the tests. Tests which were run with coal B are indicated by a star preceding the number in column 1 of the tables. The chemical characteristics and the calorific value of samples taken from the fuel of each test will be found in detail in the tables, but the following summarized statement will be convenient at this point.

Composition and calorific value of coals A and B.

	Coal A.	Coal B.
Moisture ... per cent	1.89	3.10
Volatile matter ... do	31.94	15.23
Fixed carbon ... do	57.71	72.75
Ash ... do	8.46	8.92
Heating value per pound of dry coal ... B. t. u.	14,047	14,347
Heating value per pound of combustible ... do	15,372	15,802

The cinder record, as presented in columns 23 and 24, showing the extent to which fuel passes over the heating surface of the boiler to find lodgment in the front end or to pass out of the top of the stack during each hour of the locomotive's operation, will be of more than ordinary interest to those who have not especially studied the processes which go on within a locomotive fire box.

RATES OF COMBUSTION, DRAFTS, AND SMOKE-BOX TEMPERATURES.

Rates of combustion, draft values, and smoke-box temperatures are set forth in Table 4. These are closely related factors. The rate of combustion, as expressed in terms of coal fired per square foot of grate surface per hour (column 25), is for most tests about 100 pounds. This factor, when compared with the burning of 10 to 12 pounds per foot of grate, which is common practice in stationary furnaces, well illustrates the activity of locomotive processes.

The draft is the regulator which in any boiler furnace determines the rate at which fuel shall be burned. To sustain the high rates of combustion necessary in locomotive service, high drafts are required. The drafts used in these tests are shown in column 31.

Column 32 (temperature of the smoke box) expresses the temperature at which the waste gases from the boiler are discharged. Efficient boiler action demands that the temperature of these gases shall be as low as possible, but under the high rates of combustion at which locomotive boilers are forced, the smoke-box temperatures are necessarily high, ranging in these tests from above 800° to a little less than 600° F., depending on the rate of combustion.

WATER AND STEAM.

The record of water delivered to the boiler, the boiler pressure, and the quality of the steam appear in Table 5. Thermal quantities involved in the computation of other results are given in Table 6, and the equivalent evaporation in Table 7. Column 44 shows the hourly rate at which water was actually delivered to the boiler, and column 48 the equivalent evaporation represented by the output of boiler and superheater. For most of the tests the rate of evaporation exceeded 10,000 pounds per hour, and for a considerable number it was 50 per cent or more in excess of this amount.

EVAPORATION AND HORSEPOWER.

Rates of evaporation and horsepower of boiler are shown in detail by Table 8, column 55 giving the total output of power. This value is the sum of two factors—the output of the boiler (column 53) and that of the superheater (column 54). The figures show that the normal output for the boiler and superheater is about 400 horsepower, the maximum being 482 horsepower.

EVAPORATIVE EFFICIENCY.

The evaporative efficiency is shown by Table 9. In column 56 will be found the equivalent evaporation per pound of coal as fired. The equivalent evaporation per pound of dry coal (column 57) is a usual measure of performance. The results of this column, platted with the rate of evaporation (column 51), are represented by figure 5 (p. 13). By the slope of the lines representing the experimental points for coals A and B in this figure, it will be seen that as the rate of evaporation increases the amount of water which can be evaporated per pound of coal diminishes. These lines may be accepted as fairly representing the performance of the boiler and superheater tested under all rates of power. A study of the data will show that boiler pressure, within the limits employed in the experiments, has very little influence on boiler efficiency. The evaporation per pound of combustible fired and per pound of combustible burned appears in columns 58 and 59, respectively. The significance of these two items grows out of the fact that, as will appear more plainly later, all the coal thrown into a locomotive fire box is not consumed, a considerable proportion of it finding a way of escape before complete combustion has taken place. The efficiency of the boiler is the ratio of the heat absorbed by the water to the heat available in the coal as fired. The efficiency of the boiler and grate is the ratio of the heat absorbed by the water in the boiler to the heat of combustion in the fuel fired. It appears from column 60 that the efficiency of the boiler ranged from 68 to 75 per cent; that is, the boiler and its superheater were successful in transforming these percentages of the heat energy of the fuel burned into heat energy of steam. Column 61 shows that the efficiency of the boiler and superheater, based on coal fired, ranged from 47 to 69 per cent.

CHEMICAL AND CALORIFIC VALUES.

Chemical and calorific values are given in Tables 10 to 12. These factors include the results of analyses of the smoke-box gases (columns 62 to 65); the ratio of air supplied to that required for combustion (column 70); the results of proximate and ultimate analyses of the coal used (columns 71 to 80); the percentage of combustible material found in the cinders caught in the front end, in the cinders and sparks passing out of the stack, and in the fuel dropping through the grate with the ash (columns 81 to 83); and calorific values of the coal used, of front-end and stack cinders collected, and of refuse caught in the ash (columns 84 to 88).

HEAT BALANCES.

Heat balances representing the action of locomotive boilers have justly been regarded as difficult to formulate. In the present tests

efforts were made to procure complete data on which such a balance could be based. The preceding discussion has purposely been kept

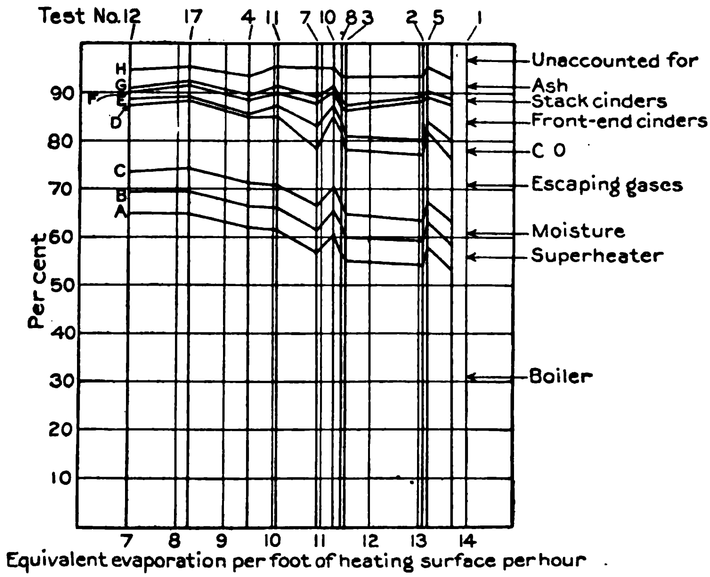

FIGURE 3.—Heat balance of combined boiler and superheater as derived from tests using coal A.

within narrow limits in the belief that the summation of the results of the tests can be most completely set forth in connection with the

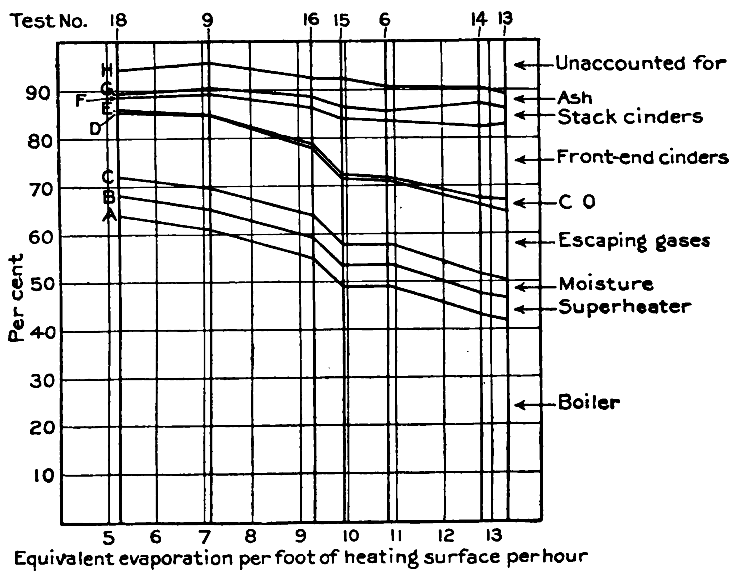

FIGURE 4.—Heat balance of combined boiler and superheater as derived from tests using coal B.

heat balances. The data making up these balances are presented in Table 13, but can be most easily understood by reference to figures 3

and 4, which show the results obtained with coal A and coal B, respectively. It is the purpose of the heat balance, as the term implies, to account for all heat represented by the coal supplied to the fire box, not only the heat which is utilized, but that which is lost, and to point out the various channels through which losses occur. In the diagrams the term "heating surface," as applied to the abscissas, includes the heat-transmitting surface of both boiler and superheater. The ordinates of the diagrams represent the percentage of heat in the fuel supplied. Distances measured on ordinates between the axis and the first broken line, A, represent the percentage of the total heat supplied which is absorbed by the water of the boiler. The line A is, in

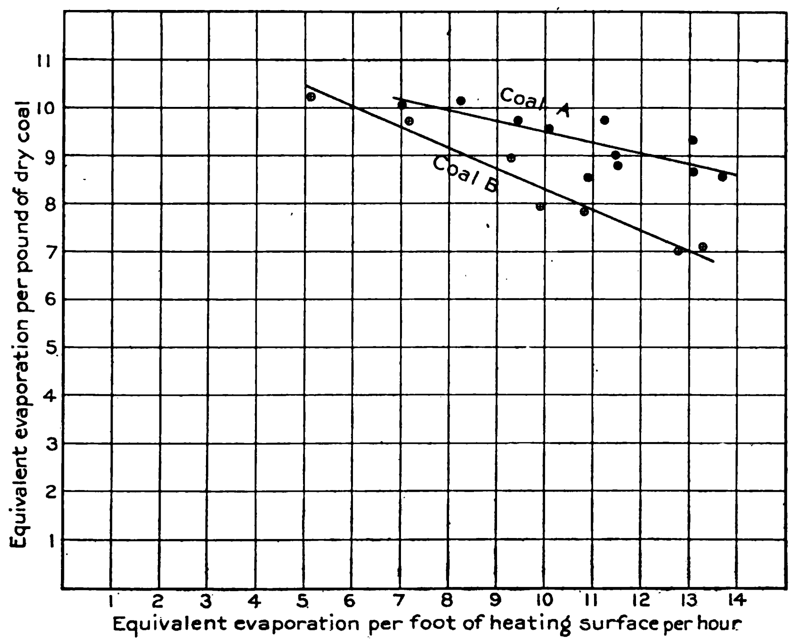

FIGURE 5.—Equivalent evaporation per pound of dry coal under all conditions of pressure.

fact, a definition of the efficiency of the boiler under the varying rates of evaporation represented by the tests. Though based on a different unit, it is, as it ought to be, similar in general form to the lines defining the evaporative efficiency of the boiler in terms of pounds of water water evaporated per pound of coal used (fig. 5). The inclination of all such lines shows the extent to which the efficiency of the boiler suffers as the rate of evaporation is increased. The nature and extent of the losses leading to decreased efficiency are to be found in the areas above the line A. The fact that the points representing different tests through which this line is drawn do not result in a smooth curve is due to irregularities in furnace conditions that were beyond the vigilance of the operator, an explanation which applies equally to other lines

of the same diagram. Again, where the points on which the line A is based fail to form a smooth curve, the reason therefor is to be found in the location of the lines above.

The percentage of the total heat which is absorbed by the superheater is measured by distances on ordinates between lines A and B. It is apparent that this quantity is practically constant, whatever may be the power to which the boiler is driven; that is, this superheater is a device of constant efficiency. The normal maximum power of a locomotive may for present purposes be taken as represented by an evaporation of 12 pounds of water per square foot of heating surface per hour. At this rate the superheater, which contains 16 per cent of the total heat-transmitting surface, receives approximately 8 per cent of the total heat absorbed. Distances between the broken line B and the axis represent the efficiency of the combined boiler and superheater, and distances above the line B account for the various heat losses incident to the operation of the furnace, boiler, and superheater.

Losses of heat arising from the presence of accidental and combined moisture in the fuel, of moisture in the atmospheric air admitted to the fire box, and of moisture resulting from the decomposition of hydrogen in the coal are represented by distances measured on ordinates between lines B and C. It is of passing interest to note that the heat thus accounted for is practically equal to that absorbed by the superheater.

Losses of heat in gases discharged from the stack are represented by distances measured on ordinates between lines C and E. The distances between lines D and E represent that portion of these losses which is due to the incomplete burning of the combustible gases. The record shows that the stack loss (C–E), while necessarily large, increases with increased rates of combustion far less rapidly than has been commonly supposed. In other words, the loss in evaporative efficiency with increase of power (line B, figs. 3 and 4) occurs only to a very slight degree through increase in the amount of heat carried away with the smoke-box gases. That portion of this loss which is chargeable to incomplete combustion (CO) is small under low rates of combustion (column 104, Table 13), but may increase to amounts of some significance under the influence of very high rates of combustion, as will be seen from the record of coal A.

Losses of heat through the discharge from the fire box of unconsumed fuel are represented by distances measured on ordinates between lines E and H. The loss thus defined is separated into three parts—the heat loss by partly consumed fuel in the form of cinders collecting in the front end (E–F), the heat loss by partly

consumed fuel in the form of cinders or sparks thrown out of the stack (F–G), and the heat lost by partly burned fuel dropping through the grate into the ash pan (G–H). The first two of these losses increase with the rate of power developed. They are, in fact, the chief cause of the decrease in the evaporative efficiency of a locomotive boiler with increased rates of power. This is well shown by a comparison of the two diagrams. In the tests with coal B (fig. 4) the cinder loss is comparatively heavy and the boiler efficiency diminishes in a marked degree under high rates of power, while tests under similar conditions with coal A (fig. 3), involving less loss

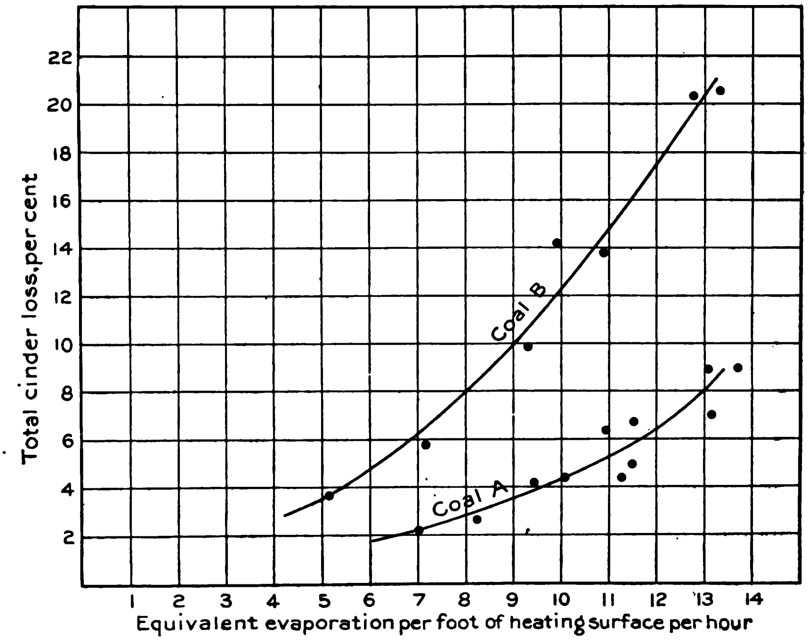

FIGURE 6.—Stack and front-end cinder loss, per cent of coal fired.

by cinders, show an efficiency of the boiler under high rates of power which is much better sustained.

The cinder loss expressed as a percentage of the total weight of coal fired is shown by figure 6, and the heating value of the material thus accounted for by figure 7. It will be seen that cinders from coal B have more than double the weight and that each pound has nearly double the heating value of those from coal A, a result doubtless due in part to the large percentage of fine material in coal B and to the absence of such material in coal A. The stack cinders from both coals have a higher calorific value than those caught in the smoke box. Under the practice of the laboratory, the coal was not wetted previous to being fired. Concerning the general sig-

nificance of the cinder loss as recorded here, it should be remembered that the fuel used in all the tests was of high quality. Lighter and more friable coals are as a rule more prolific producers of stack and front-end cinders.

Radiation, leakage, and all losses not previously accounted for are represented by distance ordinates between line H and the 100 per cent line of the diagrams. The radiation losses are probably not much in excess of 1 per cent, so that the remainder of this loss—from 3 to 8 per cent of the total heat available—represents leakage of steam or water, or inaccuracy in determining the value of one or more of the quantities already discussed.

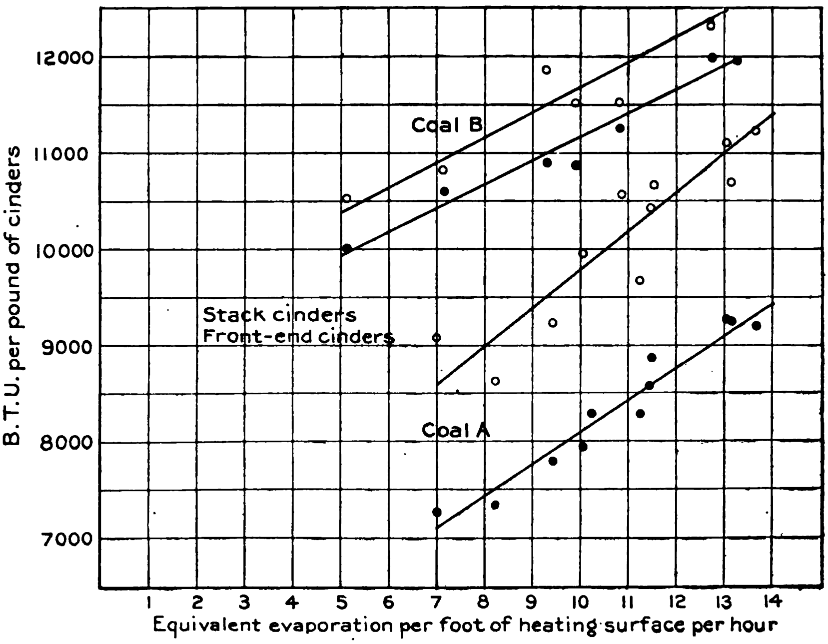

FIGURE 7.—Heat value of stack and front-end cinders.

DISTRIBUTION OF HEAT IN THE TEST LOCOMOTIVE.

It is sometimes convenient to have an elaborate statement of fact summarized into a few representative figures, the relation between which may be easily apprehended. Such a summary may be framed for the present case by assuming that the normal maximum power of the locomotive tested is that which involves a rate of evaporation of 12 pounds of water per square foot of heating surface per hour, and by averaging from the diagrams (figs. 3 and 4) the values of the various factors entering into the heat balance for this rate of power. The result may be accepted as showing in general terms the action of such a locomotive as that tested when fired with a good Pennsylvania or West Virginia coal. It is as follows:

Averaged heat balance for test locomotive.

[Percentages of total heat available.]

Absorbed by the water in the boiler	52	
Absorbed by the steam in the superheater	5	
Absorbed by steam in the boiler and superheater		57
Lost in vaporizing moisture in the coal		5
Lost through the discharge of CO		1
Lost through the high temperature of escaping gases, the products of combustion		14
Lost through unconsumed fuel in the form of front-end cinders		3
Lost through unconsumed fuel in the form of cinders or sparks passed out of the stack		9
Lost through unconsumed fuel in the ash		4
Lost through radiation, leakage of steam and water, etc		7
		100

GENERAL CONCLUSIONS.

There were in 1906, on the railroads of the United States, 51,000 locomotives. It is estimated that these locomotives consumed during the year not less than 90,000,000 tons of fuel, which is more than one-fifth of all the coal, anthracite and bituminous, mined in the country during the same period. The coal thus used cost the railroads $170,500,000.[a] That wastes occur in the use of fuel in locomotive service is a matter which is well understood by all who have given serious attention to the subject, and the tests whose results are here presented show some of the channels through which these wastes occur. These results are perhaps more favorable to economy than those attained by the average locomotive of the country, as the coal used in the tests was of superior quality, the type of locomotive employed was better than the average, and the standards observed in the maintenance of the locomotive were more exacting. But the effect on boiler performance arising from these differences is not great and, so far as they apply, the results may be accepted as fairly representative of the general locomotive practice of the country. They apply, however, only when the locomotive is running under constant conditions of operation. They do not include the incidental expenditures of fuel which are involved in the starting of fires, in the switching of engines, and in the maintenance of steam pressure while the locomotive is standing, nor do they include a measure of the heat losses occasioned by the discharge of steam through the safety valve. Observations on several representative railroads have indicated that not less than 20 per cent of the total fuel supplied to locomotives performs no function in moving trains forward. It disappears in the incidental ways just mentioned or remains in the fire box at the end of the run. The fuel consump-

[a] Rept. Interstate Commerce Commission, 1906.

tion accounted for by the heat balance on page 17 is, therefore, but 80 per cent of the total consumed by the average locomotive in service. Applied on this basis to the total consumption of coal for the country, the heat balance may be converted into terms of tons of coal as follows:

Summary of results obtained from fuel burned in locomotives.

	Tons.
1. Consumed in starting fires, in moving the locomotive to its train, in backing trains into or out of sidings, in making good safety-valve and leakage losses, and in keeping the locomotive hot while standing (estimated)	18,000,000
2. Utilized, that is, represented by heat transmitted to water to be vaporized	41,040,000
3. Required to evaporate moisture contained by the coal	3,600,000
4. Lost through incomplete combustion of gases	720,000
5. Lost through heat of gases discharged from stack	10,080,000
6. Lost through cinders and sparks	8,640,000
7. Lost through unconsumed fuel in the ash	2,880,000
8. Lost through radiation, leakage of steam and water, etc	5,040,000
	90,000,000

These amounts, together with the corresponding money value, are set forth graphically by figure 8. It is apparent from this exhibit that the utilization of fuel in locomotive service is a problem of large proportions, and that if even a small saving could be made by all or a large proportion of the locomotives of the country it would constitute an important factor in the conservation of the nation's fuel supply. On examining the diagram with reference to such a possibility the following facts are to be noted: The amount of fuel consumed in preparing locomotives for their trains, etc. (item 1), is dependent only to a very slight extent on the characteristics of the locomotive, being in large measure controlled by operating conditions, by the length of divisions, and by the promptness with which trains are moved. Under ideal conditions of operation much of the fuel thus used could be saved, and it is reasonable to expect that the normal process of evolution in railroad practice will tend gradually to bring about some reduction in the consumption thus accounted for.

The fuel required to evaporate moisture in the fuel (item 3) and that which is lost through incomplete combustion (item 4) are already small and are not likely to be materially reduced.

The loss represented by the heat of gases discharged from the stack (item 5) offers an attractive field to those who would improve the efficiency of the locomotive boiler. So long as the temperature of the discharged gases is as high as 800° F. or more there is a possibility of utilizing some of this heat by the application of smoke-box superheaters, reheaters, or feed-water heaters, though thus far the development of acceptable devices for the accomplishment of this end has made little progress.

The fuel loss in the form of cinders collecting in the front end and passing out of the stack (item 6) is very large and may readily be reduced. The results here recorded were obtained with a boiler having a narrow fire box; the losses in the form of cinders would probably be smaller with a wide fire box. A sure road to improvement in this direction lies in the direction of increased grate area. Opportunities for incidental savings are to be found in improved flame ways such as are to be procured by the application of brick arches or other devices. Such losses may also be reduced by greater care in the selection of fuel and in the preparation of the fuel for the service in which it is used. It is not unreasonable to expect that the entire loss covered by this item will in time be overcome.

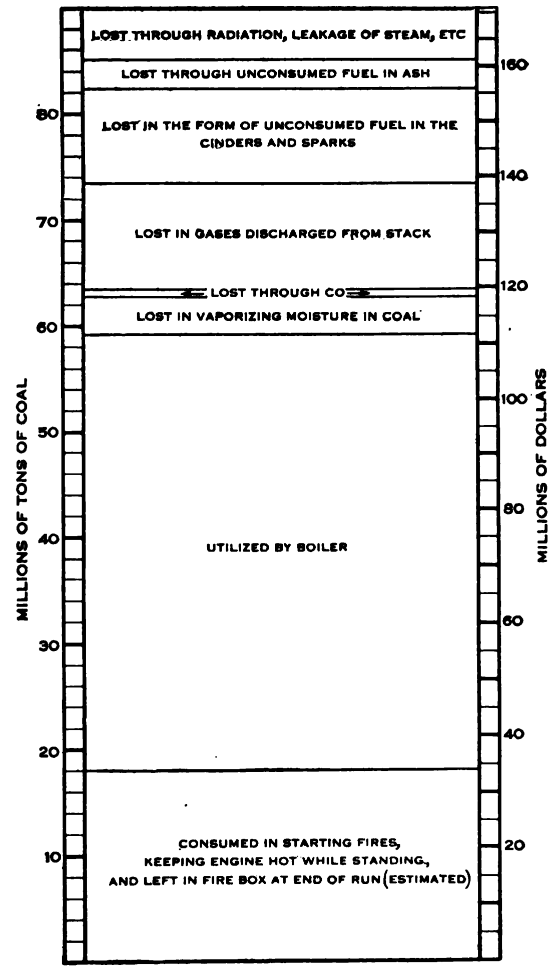

FIGURE 8.—Utilization and accompanying wastes of one year's coal supply for locomotive service in the United States.

The fuel which is lost by dropping through grates and mingling with the ash (item 7) is a factor that depends on the grate design, on the characteristics of the fuel, but chiefly on the degree of care exercised in managing the fire. More skillful firing would save much of the fuel thus accounted for.

The radiation and leakage losses (item 8) may in part be apparent rather than real, owing to possible inaccuracies in the process of developing the heat balance. On the assumption that the values are correct as stated, however, it is not likely that under ordinary conditions of service they can be materially reduced.

Locomotive boilers are handicapped by the requirement that the boiler itself and all its appurtenances must come within rigidly defined

limits of space, and by the fact that they are forced to work at very high rates of power. Notwithstanding this handicap, it is apparent that the zone of practicable improvement which lies between present-day results and those which may reasonably be regarded as obtainable is not so wide as to make future progress rapid or easy. Material improvement is less likely to come in large measures as the result of revolutionary changes than as a series of relatively small savings in the several items to which attention has been called.

TABLES.

In the tests summarized in the following tables four different boiler pressures were employed—240, 200, 160, and 120 pounds. Throughout each test the engine was operated under constant conditions, the speed and power developed being changed from test to test in accord with a fixed programme. The engine conditions were under observation, but, as has been stated, a discussion of these conditions and of the results derived from them does not come within the scope of this paper. It will be apparent to those who study the data, however, that the running conditions for tests under each of the four pressures were so chosen as to give boiler results covering a wide range of power.

TABLE 1.—*General conditions.*

No. of test.	Laboratory designation.	Date (1907).	Duration in minutes.	Duration in hours.	Temperature (°F.).				Atmospheric pressure (pounds per square inch).
					Laboratory.	Wet-bulb thermometer.	Dry-bulb thermometer.	Feed water.	
1	2	3	4	5	6	7	8	9	10
1	30-5-240	June 6	65	1.08	88.1	73.0	83.6	62.0	14.44
2	40-4-240	May 20	100	1.67	81.5	53.3	61.0	59.6	14.55
3	30-4-240	June 7	120	2.00	81.8	74.2	77.8	60.2	14.31
4	30-2-240	May 27	120	2.00	77.8	58.4	66.2	61.8	14.50
5	40-6-200	Apr. 22	150	2.50	84.5	66.7	78.1	55.3	14.42
*6	50-4-200	Apr. 12	50	.83	75.2	61.0	66.3	59.1	14.31
7	40-4-200	June 8	120	2.00	86.7	75.2	77.5	59.9	14.46
8	30-6-200	Apr. 19	150	2.50	79.3	59.1	65.6	57.2	14.45
*9	30-2-200	Mar. 18	150	2.50	72.9	64.7	73.7	55.1	14.55
10	30-8-160	Apr. 29	150	2.50	73.9	53.6	55.7	56.9	14.34
11	40-6-160	May 3	150	2.50	72.9	56.4	61.0	57.2	14.43
12	30-4-160	June 5	150	2.50	82.4	66.2	71.4	62.7	14.37
*13	40-12-120	Feb. 22	90	1.50	75.5	64.8	72.0	58.0	14.72
*14	30-14-120	Feb. 18	120	2.00	78.4	55.0	61.0	58.0	14.20
*15	30-10-120	Feb. 15	120	2.00	68.4	57.0	66.0	54.1	14.40
*16	40-8-120	Mar. 4	150	2.50	73.0	57.7	66.4	59.0	14.35
17	30-8-120	May 31	150	2.50	80.8	64.9	67.6	62.9	14.31
*18	40-4-120	Mar. 15	150	2.50	76.9	61.9	70.6	55.5	14.58

TABLE 2.—*Total coal and refuse.*

No. of test.	Laboratory designation.	Duration (hours).	Total weight (pounds) of— Coal as fired.	Dry coal fired.	Combustible fired.	Combustible consumed.	Refuse.	Front-end cinders.	Stack cinders.
1	2	5	11	12	13	14	15	16	17
1	30-5-240	1.08	2,139	2,107	1,929	1,656	157	212	29.5
2	40-4-240	1.67	3,106	3,057	2,800	2,428	210	308	44.3
3	30-4-240	2.00	3,241	3,190	2,925	2,530	360	222	45.0
4	30-2-240	2.00	2,419	2,353	2,173	1,979	206	99	57.3
5	40-6-200	2.50	4,374	4,294	3,934	3,470	324	338	73.5
*6	50-4-200	.83	1,436	1,405	1,250	989	169	293	31.6
7	40-4-200	2.00	3,157	3,099	2,741	2,385	381	195	56.8
8	30-6-200	2.50	3,918	3,859	3,529	3,153	415	211	50.8
*9	30-2-200	2.50	2,324	2,239	2,015	1,785	256	127	45.3
10	30-8-160	2.50	3,574	3,515	3,239	2,962	269	195	43.8
11	40-6-160	2.50	3,281	3,208	2,909	2,652	256	135	74.8
12	30-4-160	2.50	2,163	2,121	1,950	1,826	195	38	40.7
*13	40-12-120	1.50	3,518	3,415	3,164	2,353	231	664	157.5
*14	30-14-120	2.00	4,609	4,449	4,025	3,005	294	774	274.2
*15	30-10-120	2.00	3,119	3,030	2,742	2,135	327	454	82.2
*16	40-8-120	2.50	3,248	3,156	2,890	2,444	254	300	84.8
17	30-8-120	2.50	2,527	2,469	2,263	2,114	190	83	40.5
*18	40-4-120	2.50	1,583	1,523	1,392	1,259	205	53	24.0

TABLE 3.—*Coal and refuse per hour.*

No. of test.	Laboratory designation.	Duration (hours).	Weight per hour (pounds) of— Coal as fired.	Dry coal fired.	Combustible fired.	Combustible consumed.	Refuse.	Front-end cinders.	Stack cinders.
1	2	5	18	19	20	21	22	23	24
1	30-5-240	1.08	1,975	1,944	1,780	1,528	144	196.0	27.3
2	40-4-240	1.67	1,863	1,834	1,680	1,457	126	185.0	27.0
3	30-4-240	2.00	1,621	1,595	1,463	1,265	180	111.0	22.5
4	30-2-240	2.00	1,210	1,177	1,087	989	103	49.7	28.6
5	40-6-200	2.50	1,750	1,718	1,574	1,388	130	135.1	29.4
*6	50-4-200	.83	1,722	1,685	1,498	1,186	203	244.5	37.8
7	40-4-200	2.00	1,578	1,549	1,370	1,193	195	97.3	28.4
8	30-6-200	2.50	1,567	1,544	1,412	1,261	166	84.6	20.3
*9	30-2-200	2.50	930	896	806	714	102	50.9	18.1
10	30-8-160	2.50	1,430	1,406	1,296	1,185	108	78.2	17.5
11	40-6-160	2.50	1,312	1,282	1,163	1,060	102	54.1	29.9
12	30-4-160	2.50	866	849	780	730	78	15.3	16.3
*13	40-12-120	1.50	2,345	2,277	2,109	1,569	154	443.0	105.0
*14	30-14-120	2.00	2,304	2,224	2,012	1,502	147	387.0	137.1
*15	30-10-120	2.00	1,559	1,515	1,371	1,067	163	227.0	41.1
*16	40-8-120	2.50	1,299	1,262	1,156	978	102	120.0	34.0
17	30-8-120	2.50	1,011	988	905	846	76	33.3	16.2
*18	40-4-120	2.50	633	610	557	504	82	21.0	9.6

TABLE 4.—*Combustion, draft, and smoke-box temperature.*

No. of test.	Laboratory designation.	Duration (hours).	Dry coal fired per square foot of grate surface per hour.	Combustible fired per square foot of grate surface per hour.	Combustible consumed per square foot of grate surface per hour.	Dry coal fired per square foot of heating surface per hour.	Combustible fired per square foot of heating surface per hour.	Combustible consumed per square foot of heating surface per hour.	Draft in smoke box (inches of water).	Temperature in smoke box (°F.).
1	2	5	25	26	27	28	29	30	31	32
1	30-5-240	1.08	114.4	104.6	89.9	1.599	1.463	1.257	5.18	815.4
2	40-4-240	1.67	107.9	98.8	85.7	1.508	1.381	1.198	5.15	798.1
3	30-4-240	2.00	93.8	86.0	74.4	1.312	1.203	1.040	4.28	774.5
4	30-2-240	2.00	69.2	63.9	58.2	.968	.894	.814	3.09	725.9
5	40-6-200	2.50	101.1	92.6	81.6	1.413	1.294	1.141	5.60	824.2
*6	50-4-200	.83	99.2	88.1	69.7	1.386	1.232	.975	3.85	778.1
7	40-4-200	2.00	91.1	80.6	70.1	1.274	1.127	.981	3.69	747.1
8	30-6-200	2.50	90.8	83.1	74.2	1.270	1.161	1.037	4.37	787.0
*9	30-2-200	2.50	52.7	47.4	42.0	.737	.662	.587	2.04	661.0
10	30-8-160	2.50	82.7	76.2	69.7	1.156	1.066	.975	4.56	764.4
11	40-6-160	2.50	75.4	68.4	62.4	1.054	.956	.872	3.50	722.1
12	30-4-160	2.50	49.9	45.9	42.9	.698	.642	.601	2.25	669.6
*13	40-12-120	1.50	133.9	124.1	92.3	1.872	1.735	1.290	5.74	781.9
*14	30-14-120	2.00	130.8	118.4	88.4	1.829	1.655	1.235	5.65	771.6
*15	30-10-120	2.00	89.1	80.6	62.8	1.246	1.127	.878	3.22	701.6
*16	40-8-120	2.50	74.2	68.0	57.5	1.038	.950	.804	3.10	691.5
17	30-8-120	2.50	58.1	53.2	49.7	.812	.744	.694	3.00	676.0
*18	40-4-120	2.50	35.8	32.7	29.6	.501	.458	.414	1.25	579.1

TABLE 5.—*Water and steam.*

No. of test.	Laboratory designation.	Duration (hours).	Total water delivered to boiler.	Steam pressure by gage (pounds).	Steam temperature by thermometer (° F.).	Steam temperature corresponding to pressure (° F.).	Superheat (° F.).
1	2	5	33	34	35	36	37
1	30-5-240	1.08	13,752	236.6	552.6	401.3	151.3
2	40-4-240	1.67	20,150	239.7	556.4	402.5	153.9
3	30-4-240	2.00	21,316	238.9	554.6	402.1	152.5
4	30-2-240	2.00	17,600	241.0	540.7	402.9	137.8
5	40-6-200	2.50	30,205	200.0	565.2	387.7	177.5
*6	50-4-200	.83	8,372	201.1	547.4	388.0	159.4
7	40-4-200	2.00	20,266	199.4	540.0	387.4	152.6
8	30-6-200	2.50	26,448	200.2	556.8	387.7	169.1
*9	30-2-200	2.50	16,754	200.1	519.3	387.7	131.6
10	30-8-160	2.50	26,123	160.1	543.3	370.4	172.9
11	40-6-160	2.50	23,432	160.0	535.3	370.4	164.9
12	30-4-160	2.50	16,585	160.2	512.4	370.5	141.9
*13	40-12-120	1.50	18,483	120.6	540.5	350.2	190.3
*14	30-14-120	2.00	23,664	120.2	541.1	349.7	191.4
*15	30-10-120	2.00	18,415	119.9	524.5	349.6	174.9
*16	40-8-120	2.50	21,755	120.2	520.4	349.8	170.6
17	30-8-120	2.50	19,475	120.2	505.9	349.7	156.2
*18	40-4-120	2.50	12,231	120.1	470.6	349.8	120.8

TABLE 6.—*Thermal units.*

No. of test.	Laboratory designation.	British thermal units absorbed— Per pound of steam. By boiler.	By superheater.	By boiler and superheater.	Per minute. By boiler.	By superheater.	By boiler and superheater.
1	2	38	39	40	41	42	43
1	30-5-240	1,166.0	100.6	1,266.6	246,697	21,283	267,980
2	40-4-240	1,167.9	103.0	1,270.9	235,336	20,752	256,088
3	30-4-240	1,168.0	101.3	1,269.3	207,477	17,996	225,473
4	30-2-240	1,165.8	93.2	1,259.0	170,992	13,665	184,657
5	40-6-200	1,170.8	110.7	1,281.5	235,772	22,273	258,045
*6	50-4-200	1,165.5	101.6	1,267.1	195,152	17,012	212,164
7	40-4-200	1,165.3	96.7	1,262.0	196,787	16,339	213,126
8	30-6-200	1,168.1	106.5	1,274.6	205,963	18,775	224,738
*9	30-2-200	1,169.4	85.2	1,254.6	130,610	9,516	140,126
10	30-8-160	1,166.5	100.2	1,266.7	203,141	17,455	220,596
11	40-6-160	1,165.3	96.6	1,261.9	182,032	15,091	197,123
12	30-4-160	1,159.8	83.7	1,243.5	128,243	9,257	137,500
*13	40-12-120	1,157.4	109.9	1,267.3	237,691	22,564	260,255
*14	30-14-120	1,158.1	109.6	1,267.7	228,381	21,615	249,996
*15	30-10-120	1,160.3	102.2	1,262.5	178,053	15,694	193,747
*16	40-8-120	1,155.9	99.0	1,254.9	167,637	14,363	182,000
17	30-8-120	1,152.4	91.1	1,243.5	149,617	11,829	161,446
*18	40-4-120	1,159.8	71.6	1,231.4	94,572	5,842	100,414

TABLE 7.—*Equivalent evaporation.*

No. of test.	Laboratory designation.	Duration (hours).	Water delivered to boiler per hour (pounds).	Quality of steam in boiler.	Superheat in steam delivered (°F.).	Equivalent evaporation per hour (pounds). By boiler.	By superheater.	By boiler and superheater.
1	2	5	44	45	37	46	47	48
1	30-5-240	1.08	12,698	0.990	151.3	15,326	1,322	16,648
2	40-4-240	1.67	12,090	.989	153.9	14,620	1,289	15,909
3	30-4-240	2.00	10,658	.990	152.5	12,889	1,118	14,007
4	30-2-240	2.00	8,800	.989	137.8	10,623	849	11,472
5	40-6-200	2.50	12,082	.993	177.5	14,647	1,384	16,031
*6	50-4-200	.83	10,038	.991	159.4	12,114	1,056	13,170
7	40-4-200	2.00	10,232	.992	152.6	12,225	1,015	13,240
8	30-6-200	2.50	10,579	.992	169.1	12,795	1,166	13,961
*9	30-2-200	2.50	6,702	.991	131.6	8,114	591	8,705
10	30-8-160	2.50	10,449	.996	172.9	12,620	1,084	13,704
11	40-6-160	2.50	9,373	.995	164.9	11,309	938	12,247
12	30-4-160	2.50	6,634	.995	141.9	7,967	575	8,542
*13	40-12-120	1.50	12,322	.994	190.3	14,766	1,402	16,168
*14	30-14-120	2.00	11,832	.995	191.4	14,188	1,343	15,531
*15	30-10-120	2.00	9,208	.993	174.9	11,061	975	12,036
*16	40-8-120	2.50	8,702	.994	170.6	10,414	892	11,306
17	30-8-120	2.50	7,790	.994	156.2	9,295	735	10,030
*18	40-4-120	2.50	4,892	.994	120.8	5,875	363	6,238

TABLE 8.—*Rate of evaporation and horsepower.*

No. of test.	Laboratory designation.	Equivalent evaporation per hour (pounds). Per square foot of boiler heating surface.	Per square foot of superheating surface.	Per square foot of total heating surface.	Ratio (column 50÷column 49).	Horsepower developed per hour. By boiler.	By superheater.	By boiler and superheater.
1	2	49	50	51	52	53	54	55
1	30-5-240	14.98	6.85	13.69	0.457	444.2	38.3	482.5
2	40-4-240	14.29	6.67	13.08	.467	423.8	37.4	461.2
3	30-4-240	12.59	5.79	11.51	.460	373.6	32.4	406.0
4	30-2-240	10.39	4.40	9.43	.423	307.9	24.6	332.5
5	40-6-200	14.32	7.18	13.18	.501	424.6	40.1	464.7
*6	50-4-200	11.84	5.47	10.82	.462	351.1	30.6	381.7
7	40-4-200	11.95	5.26	10.89	.440	354.3	29.4	383.7
8	30-6-200	12.51	6.04	11.47	.483	370.9	33.8	404.7
*9	30-2-200	7.92	3.06	7.16	.386	235.2	17.1	252.3
10	30-8-160	12.33	5.61	11.26	.455	365.8	31.4	397.2
11	40-6-160	11.05	4.86	10.07	.440	327.8	27.2	355.0
12	30-4-160	7.79	2.98	7.02	.382	230.9	16.7	247.6
*13	40-12-120	14.43	7.26	13.30	.503	428.0	40.6	468.6
*14	30-14-120	13.87	6.96	12.77	.502	411.2	38.9	450.1
*15	30-10-120	10.81	5.05	9.90	.467	320.6	28.3	348.9
*16	40-8-120	10.18	4.62	9.30	.454	301.8	25.9	327.7
17	30-8-120	9.09	3.81	8.25	.419	269.4	21.3	290.7
*18	40-4-120	5.74	1.88	5.12	.328	170.3	10.5	180.8

TABLE 9.—*Economy and efficiency.*

No. of test.	Laboratory designation.	Duration (hours).	Equivalent evaporation per hour (pounds). Per pound of coal as fired.	Per pound of dry coal fired.	Per pound of combustible fired.	Per pound of combustible consumed.	Efficiency of boiler (per cent).	Efficiency of boiler and grate (per cent).
1	2	5	56	57	58	59	60	61
1	30-5-240	1.08	8.43	8.56	9.36	10.89	68.3	58.7
2	40-4-240	1.67	8.54	8.67	9.46	10.92	68.4	59.3
3	30-4-240	2.00	8.65	8.79	9.58	11.07	69.4	60.1
4	30-2-240	2.00	9.48	9.75	10.55	11.59	72.9	66.4
5	40-6-200	2.50	9.16	9.34	10.18	11.55	71.7	63.2
*6	50-4-200	.83	7.65	7.82	8.79	11.11	68.2	53.9
7	40-4-200	2.00	8.39	8.55	9.66	11.10	70.5	61.4
8	30-6-200	2.50	8.91	9.04	9.89	11.06	69.7	62.3
*9	30-2-200	2.50	9.36	9.72	10.80	12.19	74.1	65.7
10	30-8-160	2.50	9.59	9.75	10.57	11.57	72.4	66.2
11	40-6-160	2.50	9.34	9.55	10.53	11.55	72.6	66.2
12	30-4-160	2.50	9.87	10.06	10.95	11.70	73.8	69.0
*13	40-12-120	1.50	6.89	7.10	7.67	10.30	62.7	46.7
*14	30-14-120	2.00	6.74	6.98	7.72	10.33	63.5	47.4
*15	30-10-120	2.00	7.72	7.95	8.78	11.27	68.9	53.6
*16	40-8-120	2.50	8.70	8.96	9.78	11.56	70.9	60.0
17	30-8-120	2.50	9.92	10.16	11.08	11.87	74.7	69.7
*18	40-4-120	2.50	9.85	10.23	11.20	12.38	75.3	68.1

TABLE 10.—*Dry-gas analyses and air supply.*

No. of test.	Laboratory designation.	Gas analyses. CO_2.	Gas analyses. O.	Gas analyses. CO.	Gas analyses. N.	Weight (pounds) of— Dry gas per pound of carbon burned.	Dry gas per pound of combustible fired.	Air per pound of carbon burned.	Air per pound of combustible fired.	Ratio of air supplied to theoretical requirement.
1	2	62	63	64	65	66	67	68	69	70
1	30-5-240	14.63	2.98	1.06	81.33	16.18	11.31	15.71	10.98	1.16
2	40-4-240	13.95	3.81	.99	81.25	16.95	11.96	16.48	11.63	1.22
3	30-4-240	14.11	4.32	.77	80.80	17.04	12.32	16.45	11.89	1.25
4	30-2-240	14.27	4.05	.12	81.55	17.63	13.41	17.17	13.06	1.23
5	40-6-200	13.90	3.87	.40	81.83	17.70	13.09	17.54	12.98	1.22
*6	50-4-200	13.59	5.16	.10	81.15	18.49	12.64	17.96	12.28	1.32
7	40-4-200	14.63	3.01	1.39	80.97	15.85	11.36	15.32	10.98	1.16
8	30-6-200	13.64	4.72	.27	81.37	18.20	13.52	17.73	13.17	1.28
*9	30-2-200	11.70	7.40	.01	80.90	21.47	16.95	20.94	16.53	1.53
10	30-8-160	13.48	5.14	.31	81.07	18.35	14.13	17.82	13.73	1.32
11	40-6-160	12.85	5.81	.35	80.99	19.12	14.58	18.59	14.18	1.37
12	30-4-160	12.47	6.11	.29	81.13	19.75	15.32	19.27	14.94	1.40
*13	40-12-120	12.05	6.34	.27	81.33	20.41	13.08	20.00	12.81	1.42
*14	30-14-120	11.82	6.77	.16	81.25	21.01	13.66	20.58	13.37	1.46
*15	30-10-120	11.57	7.15	.15	81.12	21.43	14.33	20.97	14.02	1.50
*16	40-8-120	11.99	7.43	.04	80.51	20.92	15.45	20.27	14.97	1.54
17	30-8-120	12.20	6.15	.19	81.46	20.31	15.67	19.92	15.37	1.40
*18	40-4-120	10.81	8.82	.11	80.26	22.96	17.88	22.26	17.35	1.71

TABLE 11.—*Coal analyses.*

No. of test.	Laboratory designation.	Proximate analysis. Moisture.	Volatile matter.	Fixed carbon.	Ash.	Ultimate analysis of dry coal. Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
1	2	71	72	73	74	75	76	77	78	79	80
1	30-5 240	1.54	31.67	58.53	8.26	77.02	4.66	7.24	1.52	1.17	8.39
2	40-4-240	1.56	31.16	59.01	8.29	76.83	4.62	7.44	1.57	1.14	8.40
3	30-4-240	1.63	31.74	58.49	8.14	78.70	4.73	5.67	1.51	1.11	8.28
4	30-2-240	2.72	32.19	57.63	7.46	78.45	5.25	6.10	1.50	1.03	7.67
5	40-6-200	1.83	32.85	57.09	8.22	78.60	4.76	5.64	1.52	1.10	8.38
*6	50-4-200	2.16	15.88	71.18	10.77	79.45	3.92	3.69	1.03	.94	11.00
7	40-4-200	1.84	30.70	56.13	11.33	74.91	4.89	6.02	1.45	1.19	11.54
8	30-6-200	1.51	32.78	57.27	8.44	77.76	4.71	6.48	1.50	1.08	8.57
*9	30-2-200	3.68	15.56	71.10	9.66	81.30	4.09	2.52	1.04	1.04	10.00
10	30-8-160	1.65	32.94	57.70	7.71	78.90	4.88	5.68	1.54	1.16	7.84
11	40-6-160	2.24	32.33	56.28	9.15	77.09	4.82	6.12	1.52	1.09	9.36
12	30-4-160	2.01	31.39	58.67	7.93	77.14	4.52	7.43	1.55	1.27	8.09
*13	40-12-120	2.93	15.27	74.66	7.14	83.14	4.16	3.52	1.08	.75	7.35
*14	30-14-120	3.44	14.55	72.80	9.21	81.72	4.17	2.67	1.00	.91	9.54
*15	30-10-120	2.85	14.70	73.26	9.19	80.54	4.10	3.90	1.05	.95	9.46
*16	40-8-120	2.82	15.11	73.86	8.21	81.74	4.11	3.83	1.02	.84	8.44
17	30-8-120	2.30	31.53	58.03	8.14	76.65	4.61	7.58	1.57	1.26	8.33
*18	40-4-120	3.79	15.55	72.39	8.27	79.93	3.87	5.57	1.05	.98	8.60

TABLE 12.—*Chemical analyses and calorific values.*

No. of test.	Laboratory designation.	Per cent of combustible—			Calorific value (British thermal units).				
		In front-end cinders.	In stack cinders.	In refuse from ash pan.	Per pound of dry coal.	Per pound of combustible.	Per pound of stack cinders.	Per pound of front-end cinders.	Per pound of refuse from ash pan.
1	2	81	82	83	84	85	86	87	88
1	30-5-240	79.83	66.08	53.76	14,097	15,388	11,239	9,211	7,849
2	40-4-240	78.03	63.89	49.03	14,121	15,416	11,113	9,275	7,160
3	30-4-240	81.98	61.86	51.94	14,124	15,398	10,673	8,881	7,583
4	30-2-240	66.10	60.61	45.88	14,174	15,352	9,245	7,812	6,698
5	40-6-200	76.30	65.52	48.85	14,262	15,566	10,699	9,265	7,132
*6	50-4-200	80.63	80.24	41.81	14,009	15,744	11,534	11,261	6,103
7	40-4-200	73.61	70.33	44.14	13,457	15,214	10,571	9,949	6,444
8	30-6-200	73.84	60.12	45.73	14,018	15,332	10,442	8,599	6,677
*9	30-2-200	74.14	74.79	39.85	14,283	15,875	10,832	10,615	5,820
10	30-8-160	64.82	57.02	46.94	14,216	15,425	9,293	8,305	6,853
11	40-6-160	69.97	56.38	47.19	13,914	15,351	9,959	7,960	6,890
12	30-4-160	64.87	57.47	39.25	14,062	15,300	9,090	7,272	5,730
*13	40-12-120	87.95	82.51	41.73	14,690	15,857	12,627	11,980	6,092
*14	30-14-120	86.42	83.13	41.87	14,215	15,714	12,337	12,000	6,114
*15	30-10-120	80.55	75.38	54.73	14,305	15,799	11,534	10,875	7,984
*16	40-8-120	83.09	75.52	51.82	14,421	15,752	11,875	10,903	7,565
17	30-8-120	68.50	59.27	35.81	14,070	15,348	8,640	7,349	5,228
*18	40-4-120	74.74	70.00	37.60	14,507	15,872	10,546	10,115	5,490

TABLE 13.—*Heat balances.*

No. of test.	Laboratory designation.	Calorific value (British thermal units per pound of combustible).	British thermal units absorbed per pound of combustible fired.	British thermal units lost per pound of combustible fired.								
				Due to H_2O in coal.	Due to H_2O in air.	Due to H_2O formed by H in coal.	Due to escaping gases.	Due to incomplete combustion.	Due to front-end cinders.	Due to stack cinders.	Due to refuse in ash pan.	Unaccounted for.
1	2	85	89	90	91	92	93	94	95	96	97	98
1	30-5-240	15,388	9,040	24	70	632	1,975	576	1,235	141	639	1,056
2	40-4-240	15,416	9,136	24	33	625	2,057	565	1,224	147	537	1,068
3	30-4-240	15,398	9,252	25	82	633	2,049	451	886	137	933	950
4	30-2-240	15,352	10,189	41	39	688	2,087	72	432	205	634	965
5	40-6-200	15,566	9,832	28	62	649	2,325	243	918	173	588	748
*6	50-4-200	15,744	8,489	34	55	544	2,133	66	1,882	284	823	1,434
7	40-4-200	15,214	9,330	29	75	671	1,801	746	750	206	895	711
8	30-6-200	15,332	9,552	23	47	637	2,297	167	625	124	785	1,075
*9	30-2-200	15,875	10,430	56	58	541	2,392	8	670	243	738	739
10	30-8-160	15,425	10,209	25	42	653	2,342	195	561	112	570	716
11	40-6-160	15,351	10,170	34	42	646	2,272	229	463	205	604	686
12	30-4-160	15,300	10,575	28	57	581	2,160	194	178	152	573	802
*13	40-12-120	15,857	7,408	45	55	556	2,217	199	2,654	596	445	1,680
*14	30-14-120	15,714	7,456	54	44	568	2,272	122	2,373	817	446	1,562
*15	30-10-120	15,799	8,480	43	43	547	2,178	116	1,910	326	948	1,208
*16	40-8-120	15,752	9,446	42	44	538	2,294	30	1,233	320	665	1,140
17	30-8-120	15,348	10,701	34	59	597	2,239	130	270	132	439	747
*18	40-4-120	15,872	10,817	55	46	486	2,145	89	400	174	807	833

TABLE 13.—*Heat balances*—Continued.

No. of test.	Laboratory designation.	Percentage of heat— Absorbed by boiler and superheater.	Due to H_2O in coal.	Due to H_2O in air.	Due to H_2O formed by H in coal.	Due to escaping gases.	Due to incomplete combustion.	Due to front end cinders.	Due to stack cinders.	Due to refuse in ash pan.	Unaccounted for.
1	2	99	100	101	102	103	104	105	106	107	108
1	30-5-240	58.75	0.16	0.46	4.11	12.83	3.74	8.02	0.92	4.15	6.86
2	40-4-240	59.28	.15	.20	4.05	13.35	3.67	7.94	.95	3.48	6.93
3	30-4-240	60.08	.16	.53	4.11	13.31	2.93	5.75	.89	6.06	6.17
4	30-2-240	66.37	.27	.25	4.48	13.58	.47	2.81	1.34	4.13	6.30
5	40-6-200	63.16	.18	.40	4.17	14.93	1.56	5.00	1.11	3.78	4.81
*6	50-4-200	53.90	.22	.35	3.45	13.32	.42	11.96	1.80	5.23	9.37
7	40-4-200	61.34	.19	.49	4.41	18.86	4.90	4.95	1.35	5.88	4.63
8	30-6-200	62.34	.15	.31	4.16	14.98	1.09	4.08	.81	5.12	6.96
*9	30-2-200	65.70	.35	.37	3.41	15.07	.05	4.22	1.53	4.65	4.65
10	30-8-160	66.16	.16	.27	4.24	15.18	1.27	3.64	.73	3.70	4.65
11	40-6-160	66.25	.22	.27	4.21	14.79	1.49	3.02	1.33	3.93	4.49
12	30-4-160	69.12	.18	.37	3.80	14.11	1.27	1.16	.99	3.74	5.26
*13	40-12-120	46.72	.28	.35	3.51	13.98	1.26	16.74	3.76	2.81	10.59
*14	30-14-120	47.45	.34	.28	3.61	14.46	.78	15.10	5.20	2.84	9.94
*15	30-10-120	53.67	.27	.27	3.46	13.78	.73	12.09	2.06	6.00	7.67
*16	40-8-120	59.97	.26	.27	3.42	14.56	.19	7.82	2.03	4.22	7.26
17	30-8-120	69.73	.22	.38	3.89	14.58	.85	1.76	.86	2.86	4.87
*18	40-4-120	68.14	.35	.29	3.06	13.58	.56	2.52	1.10	5.09	5.31

SURVEY PUBLICATIONS ON FUEL TESTING.

The following publications, except those to which a price is affixed, can be obtained free by applying to the Director, Geological Survey, Washington, D. C. The priced publications can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

BULLETIN 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

PROFESSIONAL PAPER 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge, 1906. In three parts. 1,492 pp., 13 pls. $1.50.

BULLETIN 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

BULLETIN 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp. 10 cents.

BULLETIN 325. A study of four hundred steaming tests, made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp. 20 cents.

Bulletin 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes, in charge. 1908. 299 pp. 25 cents.

Bulletin 334. The burning of coal without smoke in boiler plants; a preliminary report, by D. T. Randall. 1908. 26 pp. 5 cents.

Bulletin 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. 76 pp. 10 cents.

Bulletin 339. The purchase of coal under government and commercial specifications on the basis of its heating value, with analyses of coal delivered under government contracts, by D. T. Randall. 1908. 27 pp. 5 cents.

Bulletin 343. Binders for coal briquets, by J. E. Mills. 1908. 56 pp.

Bulletin 362. Mine sampling and chemical analyses of coals tested at the United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp. 5 cents.

Bulletin 363. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1908. 57 pp., 4 pls.

Bulletin 366. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 1908. 44 pp., 3 pls.

Bulletin 367. Significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 1909. 61 pp.

Bulletin 368. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. R. Delamater, and J. W. Groves. 1909. 54 pp., 2 pls.

Bulletin 373. The smokeless combustion of coal in boiler plants, by D. T. Randall and H. W. Weeks. 1909. 188 pp.

Bulletin 385. Briquetting tests at Norfolk, Va., by C. L. Wright. 1909. 41 pp., 9 pls.

Bulletin 392. Gasoline and alcohol tests on internal-ignition engines, by R. M. Strong. 1909. 38 pp.

Bulletin 393. Incidental problems in gas-producer tests, by R. H. Fernald and others. 1909. 29 pp.

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 403

COMPARATIVE TESTS
OF
RUN-OF-MINE AND BRIQUETTED COAL
ON THE
TORPEDO BOAT BIDDLE

Made with the collaboration of Lieut. Commander Kenneth McAlpine, U. S. N., and Ensign J. W. Hayward, U. S. N.

BY

WALTER T. RAY AND HENRY KREISINGER

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COMPARATIVE TESTS OF RUN-OF-MINE AND BRIQUETTED COAL ON THE TORPEDO BOAT BIDDLE.

By WALTER T. RAY and HENRY KREISINGER.

INTRODUCTION.

General statement.—The briquetting tests conducted by the United States Geological Survey had their beginning in the testing of coals and lignites at the Louisiana Purchase Exposition, St. Louis, Mo., in 1904, and were continued at the fuel-testing plants at St. Louis, Mo., and at Norfolk, Va. Such tests are now in progress at the Geological Survey testing station at Pittsburg, Pa., and form an essential part of the Survey's investigations looking to the determination of the fuel value of the coals and lignites belonging to or for the use of the United States.

The tests have comprised (1) the manufacture of briquets to determine the adaptability of different coals and lignites to the process and the merits of different binding materials; (2) physical tests to establish the fitness of the briquets to withstand weathering, transportation, and handling; and (3) steaming tests to prove the calorific value of the briquets in boilers of different types used by the Government, and, by comparison with the raw coals, the benefits to be derived from briquetting.

Details of the tests are issued by the Survey in other publications. A list of Survey publications on fuel testing and briquetting is given at the close of this volume.

Tests at Norfolk.—The fuel tests conducted at Norfolk included a detailed investigation of a number of Virginia and West Virginia coals that are bought by the United States Government for the navy and for use in constructing the Panama Canal, and that are extensively used by the merchant marine, manufacturing plants, and railroads. Through a cooperative arrangement with the Navy Department steaming tests of the coals were undertaken to determine the relative merits of the same coal when burned raw or as briquets in marine boilers.

Preliminary arrangements were made between Joseph A. Holmes, expert in charge of the technologic branch of the United States

Geological Survey, and Rear-Admiral Charles W. Rae, Chief Engineer of the United States Navy. The tests were made on board the U. S. torpedo boat *Biddle,* designated for the purpose, beginning December 6, 1907, and ending January 27, 1908.

The coal used in these tests came from the Sewell and Beckley beds in the New River district of West Virginia. With the particular equipment used in the tests both coal and briquets were far from smokeless; consequently the data of this bulletin are applicable only by analogy to parallel operation with a coal more nearly smokeless, but nevertheless applicable with much reliability. The possibilities of coals of different composition are indicated by the data to be published in a bulletin of the Geological Survey now in preparation, wherein the present authors describe a number of tests in which only a very slight amount of smoke was emitted while burning raw coal from the Pocahontas No. 3 bed, West Virginia, and briquets made therefrom at rates of combustion very much higher than any rates used in the torpedo-boat boiler. At a combustion rate of 120 pounds of the Pocahontas briquets per square foot of grate surface there was scarcely any smoke.

It was the original intention to make a set of preliminary steaming tests alongside a dock (which tests furnish material for this bulletin) and to finish with a set of running tests at sea; but the running tests were never made, for lack of time and men.

PERSONNEL.

The conduct of the tests, on behalf of the navy, was under the immediate supervision of Lieut. Commander Kenneth McAlpine assisted by Ensign J. W. Hayward, in command of the *Biddle.* The Geological Survey was represented by Walter T. Ray and Henry Kreisinger of the steam-engineering section.

Messrs. McAlpine and Hayward directed the preparation of the boat and other apparatus for the tests and had all the special appliances made in the navy-yard shops. All tests were supervised by Messrs. Hayward and Kreisinger. The navy supplied water tenders, firemen, and a number of machinists. The latter acted as observers and recorders of pressures, temperatures, and weight of water. Weight of coal fired was recorded currently by Mr. Kreisinger, who supervised the management of fires. Flue-gas analyses were made usually by a representative of the Geological Survey; many of them were made by J. K. Clement, physicist of the technologic branch, who very kindly volunteered to help with the work during the first eight tests. The flue-gas analyses on the rest of the tests were made by Mr. Ray. Firing on all the tests was done by the navy firemen, who were found to be exceptionally skillful in this work.

COALS AND BRIQUETS.

The coal used in these tests was all run-of-mine and came from four different mines, all of which are located on the Chesapeake and Ohio Railway and in the New River coal field. The designations given these four coals at the United States fuel-testing plant are followed in this bulletin.

Jamestown No. 6 coal came from the Sewell bed at Red Star, Fayette County, W. Va. Jamestown No. 9 coal came from the Sewell bed, mined near Winona, Fayette County, W. Va. Jamestown No. 10 coal came from the Beckley bed, at Stanaford, Raleigh County, W. Va. Jamestown No. 11 coal came from the Beckley bed, at West Raleigh, Raleigh County, W. Va.

Part of the Jamestown 6 coal was made into briquets 6¾ by 4½ by 3 inches in size, at the United States fuel-testing plant on a briquetting press built in England. The compression on these large briquets was about 2,500 pounds per square inch. The binder used was 6 per cent of water-gas pitch, described in Bulletin 385[a] under laboratory number 5563.

Portions of the Jamestown 9 and 11 coals were made into briquets circular in horizontal section, 3½ inches in diameter, 2⅜ inches thick in the center and 1½ inches at the circumference. The compression on these small briquets was about 1,000 pounds per square inch. In both coals the binder used was 6 per cent of water-gas pitch, described in Bulletin 385[a] under laboratory number 5941.

OBJECTS OF THE TESTS.

The main object of these tests was to determine whether the use of briquetted coal on torpedo boats has any advantages over the use of raw coal. Besides comparing the economy obtained with briquetted and raw coal, the following properties of the two fuels were given particular attention: (*a*) The tendency to smoke; (*b*) the amount of sparks emitted from the stack; (*c*) the rate at which steam can be made and the ease with which the fires are handled; (*d*) the ease of transferring fuel from the coal bunkers into the fireroom.

APPLIANCES.

BOAT AND BOILER PLANT.

The torpedo boat *Biddle* is 157 feet in length on load water line, 17 feet 7½ inches extreme beam, and 175 tons displacement. Its equipment includes two triple-expansion engines and two water-tube

[a] Wright, Charles L., Briquetting tests at the United States fuel-testing plant, Norfolk, Va., 1907-8: Bull. U. S. Geol. Survey No. 385, 1909, p. 8.

boilers. The engines are in separate compartments amidships. The boilers are in separate boiler rooms, one at each end of the engine compartments, the fronts of the boilers facing the latter. In front of each boiler is a space about 10 feet square used as the fireroom, in which is placed an auxiliary feed pump and the wheel of a blower fan. The blower is run by the engine in the main compartment. Alongside each boiler room are two coal bunkers, each capable of holding about 22.5 tons of soft coal. In cross section each coal bunker is approximately a segment of a circle with the chord of the segment placed vertically and with its tips cut off by the deck and the floor of the bunker. This floor of the bunker is, however, only about 8 to 12 inches wide, which fact, in connection with the ribs of the sides of the boat projecting inward, makes shoveling coal from the bunker rather difficult. Two feed-water reserve tanks alongside the engine compartments, of shapes similar to those of the coal bunkers, have each a water capacity of about 700 gallons.

The two boilers are exactly alike in size, construction, and setting (fig. 1). Only the forward boiler was used for tests. It is of the curved water-tube type known as the Normand boiler. The boiler proper consists of the steam drum S, connected to two mud drums M by 1,552 curved water tubes $1\frac{3}{16}$ inches in external diameter and two $10\frac{3}{4}$-inch downcomers in the rear of the boiler. The steam drum is provided with a steam dome in which the intake of the steam pipe is placed. Feed water is fed into the steam drum.

The furnace is placed under the steam drum between the two nests of water tubes and the mud drums. It is equipped with a plain grate for hand firing. The coal is charged through two firing doors 12 by 14 inches, the lower edges of which are 14 inches above the grate, which feature of construction makes the process of removing clinker from the fuel bed while running rather difficult. In the front portion of the boiler on both sides the first and second rows of tubes next the furnace are so curved and placed with respect to each other that they form a nearly gas-tight baffle. On the outside of each nest of tubes the last two rows are similarly placed along the full length of the boiler. This constructional feature is shown in figure 1 in the front view and in the section across the nest of tubes.

The products of combustion flow to the rear of the furnace, where they enter the tube nests through the spaces between the tubes, which are left open for this purpose. Through the nests of tubes the gases flow to the front of the boiler and there turn up into the hood and out through the stack. The gases pass through the tube spaces only once. The path of the gases is indicated in the longitudinal section through the boiler.

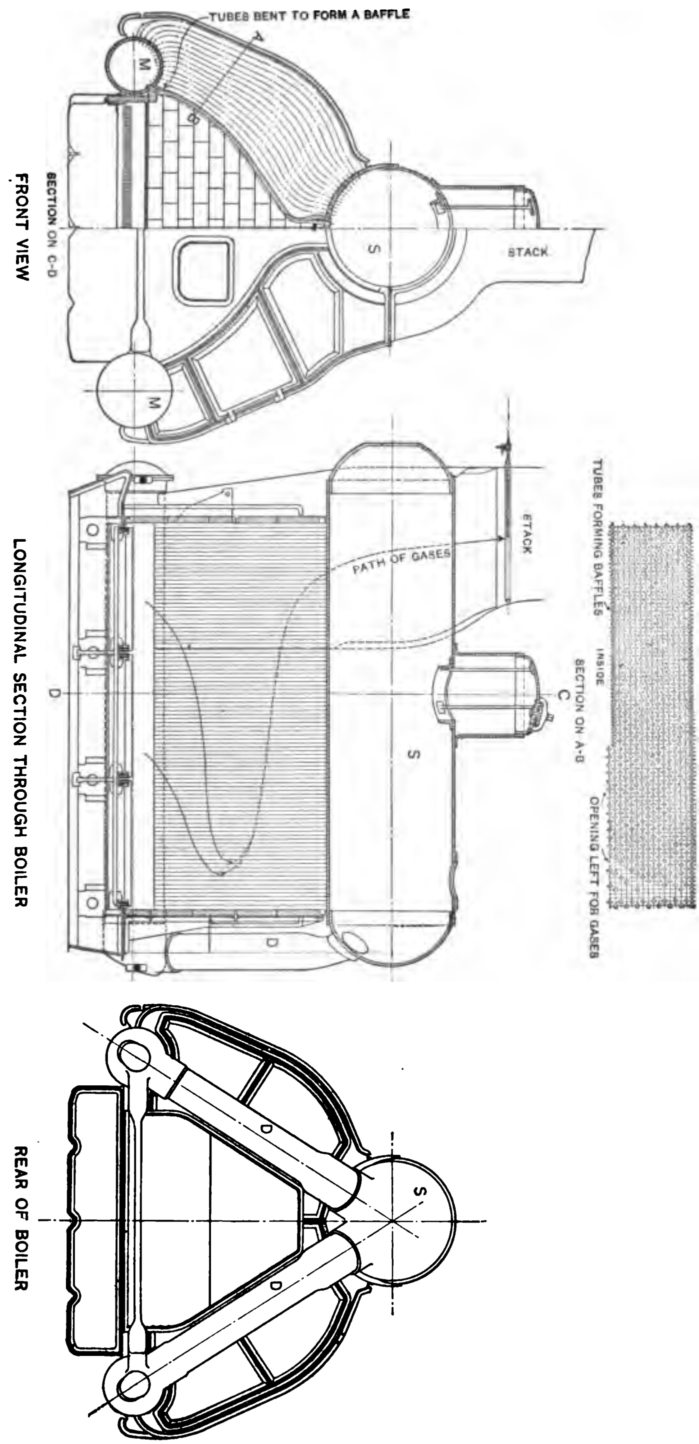


FIGURE 1.—Construction and setting of Normand water-tube boiler.

The principal dimensions of the boiler and furnace are shown in Table 1.

TABLE 1.—*Dimensions of Normand water-tube boiler and plain-grate furnace.*

Diameter of steam drum .... inches..	35.43
Length of steam drum .... do....	150.00
Diameter of mud drums .... do....	10.75
Length of mud drums .... do....	141.75
Diameter of downcomers .... do....	10.75
Number of tubes	1,552
Outside diameter of tubes .... inches..	$1\frac{3}{16}$
Approximate length of tubes .... do....	75.5
Total heating surface .... square feet..	2,776.19
Length of furnace .... feet..	9.16
Width of furnace .... do....	6.40
Height of furnace from grate to steam drum .... do....	4.65
Height of furnace from grate to bend of tubes .... do....	3.76
Approximate combustion space above grate .... cubic feet..	136
Distance from front of furnace to opening among tubes .... feet..	5.5
Length of bars .... inches..	37.5
Average width of grate bars on top .... do....	.375
Average width of air spaces .... do....	.56
Air spaces in grate (approximate) .... per cent..	.55
Area of grate .... square feet..	58.6
Ratio of grate area to combustion space	2.33
Inner dimensions of stack .... inches..	36 x 40
Height of stack above grate .... feet..	15

The whole boiler and furnace were inclosed in a cast-iron casing, which was lined with fire brick at the front and rear of the combustion space and with sheet asbestos along the nests of tubes. In front the casing had tight-fitting doors opening into the tube nests to facilitate the cleaning of soot from the tubes.

The stack, which was slightly elliptical in cross section, was made of two concentric tubes with $1\frac{1}{2}$-inch annular air space between, open to the air at the top and also at the base of the stack. The object of this construction was to circulate air between the inner and outer tubes, thus keeping the outer shell cool.

FLUE-GAS SAMPLER.

The flue-gas sampler was inserted in the stack immediately above the hood, as shown in the longitudinal cross section (fig. 1). The sampler was especially made for these tests and consisted of a $\frac{3}{4}$-inch pipe closed at both ends and having a number of $\frac{3}{32}$-inch holes drilled in a staggered way on two opposite sides of the pipe. Through a cap closing one of the ends of this pipe was inserted a $\frac{1}{4}$-inch pipe, which extended to the middle of the $\frac{3}{4}$-inch pipe. The gas was drawn through the inner pipe. The object of this construction was to draw gas at nearly the same rate from many places in the stack,

so that the gas thus collected may be taken as a rough average of the gases flowing up through the stack. The construction of this sampler is shown in figure 2. Connection was made to a steam injector, which drew a continuous stream of gas through the sampler. The sample collected for analysis was drawn through a pet cock placed between the sampler and the injector.

SPARK CATCHERS.

Figure 3 shows four spark catchers in position, as used during the tests. Each spark catcher consists of a U-shaped sheet-iron vessel open at both ends and placed with the open ends down over the top of the stack. The end inside the stack is in shape nearly a sector of a circle covering an angular area of 9 degrees, so that the total area covered by the four spark catchers is 0.1 of the total cross-sectional area of the stack. The outside end of the U-shaped vessel is nearly rectangular in cross section and terminates in a detachable sheet-iron receptacle. This U-shaped vessel catches gases and sparks from a sector of the stack area and changes their direction downward. The gases are allowed to escape through an opening in the outside end of the U-shaped vessel, which opening is provided with wire netting of 24 meshes to an inch. The sparks are kept in by the wire netting and fall into the

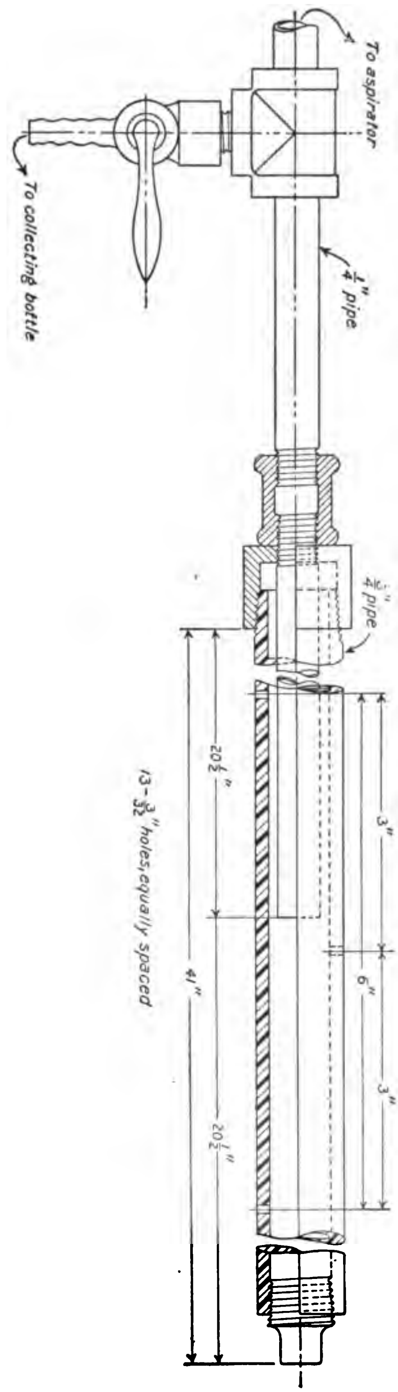
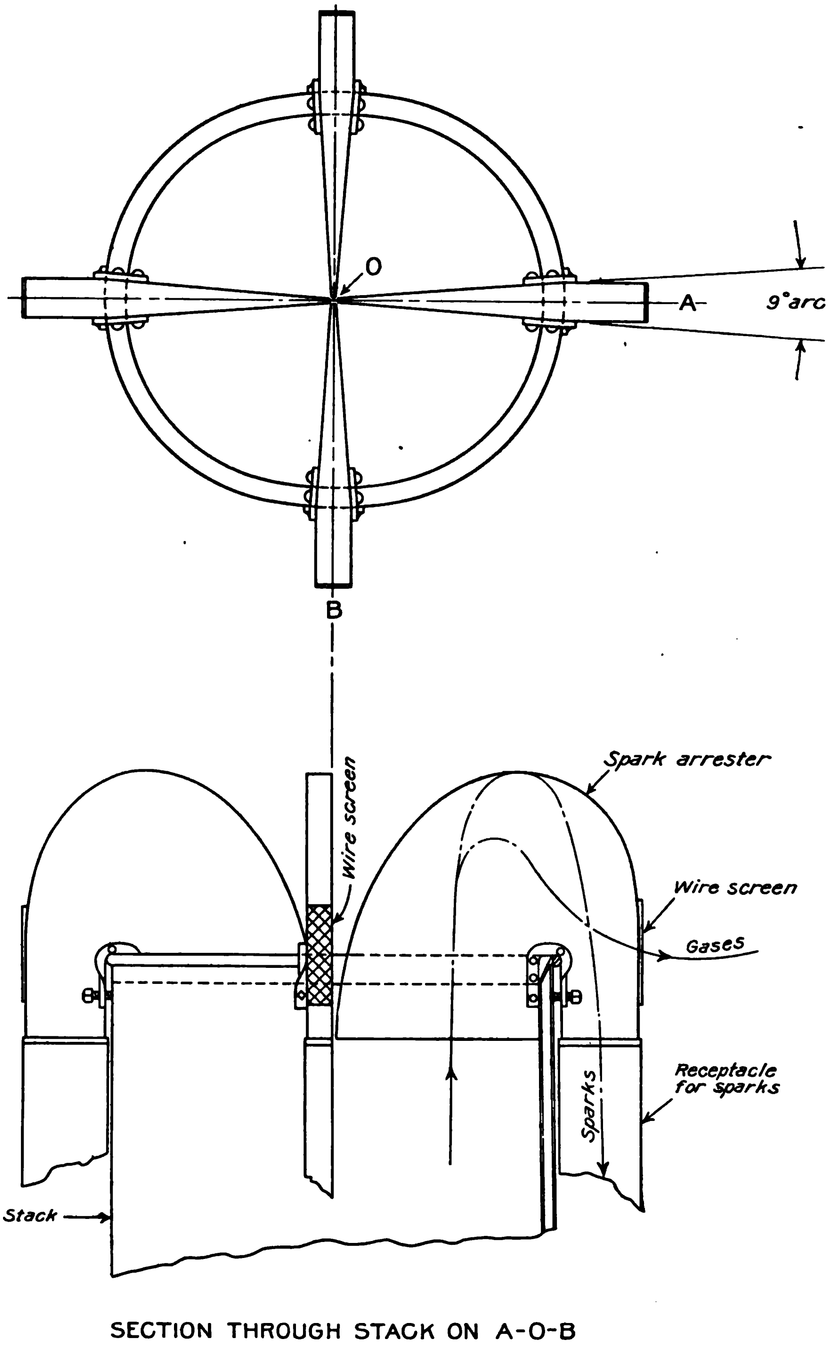


FIGURE 2.—Flue-gas sampler.



SECTION THROUGH STACK ON A-O-B

FIGURE 3.—Spark catchers.

receptacle, where they accumulate. As these spark catchers cover about 0.1 of the area of the stack, the amount of sparks collected in the receptacle is about 0.1 of the total sparks ejected from the stack.

These spark catchers were specially designed and constructed for these tests in order to determine the comparative losses in sparks when burning raw coal and the two kinds of briquets.

THE BLOWER.

The necessary air required for the combustion of the fuel in the furnace was supplied by a blower which forced air into the fireroom, which was kept as nearly air-tight as practicable. Thus, by changing the speed of the blower, any desired excess of pressure over the outside atmosphere could be kept in the fireroom and under the grate, and within certain limits any rate of combustion could be obtained.

The wheel of the blower was 5 feet in diameter and was placed directly in the fireroom; it had no casing and was protected only by a wire screen. The blades were curved in the direction opposite to that of the rotation of the wheel. The maximum speed of the blower was about 1,000 revolutions per minute.

METHODS OF CONDUCTING TESTS.

General statement.—All tests were made using the forward boiler while the boat was tied to the docks at the Norfolk Navy-Yard. Steam was generated at 200 pounds pressure and discharged into the atmosphere. The water tender on duty also regulated the steam pressure in the boiler. During a test all regular observations were made every twenty minutes.

Starting and closing.—In starting and closing the tests a modification of the "alternate method" was used. The boiler was kept under steam pressure all night with a low fire covering the front third of the grate. About one hour before starting a test the fire was spread over the whole grate and gradually built up to 3 or 4 inches height. During this building of the fire about 500 pounds of coal were put into the furnace. On starting the test the height of the fuel bed was measured as accurately as possible with the prongs of a rake, and readings were taken of the steam pressure and height of water in the boiler. The reserve water tank from which the boiler was fed was always completely filled when a test was started. Closing conditions of the tests were made as nearly as possible the same as those of starting.

Weight of ash and refuse.—Before closing a test the fuel bed was burned down so that its height above the layer of clinker was the same as at the start, as nearly as could be estimated by means of the

prongs of a rake. The test was started with the ash pan clean. After closing the test the free ash was removed from the ash pan, weighed, and charged to the test. The fire was then burned down entirely, the clinkers pulled out through the fire doors, weighed, and also charged to the test. The small amount of free ash falling into the ash pan during the process of pulling out clinkers was not charged to the test. It was impracticable to clean the fire before the close of the test on account of the lower edge of the fire door being 14 inches above the grate.

Weight of coal fired.—The fireroom was so small that it was impossible to place a scale in it and weigh the coal as it was fired; therefore on most of the tests the coal was weighed before the test and put in sacks of 100 pounds each and delivered to the coal bunkers. During the test 3 or 4 sackfuls of coal were emptied on the floor of the fireroom and fired in two to four firings. The number of sackfuls and the time of emptying them were recorded. This method of recording coal enabled the man having charge of the fire to keep the rate of combustion uniform. In a few tests a definite amount of the coal was weighed before the test and put into an empty coal bunker without sacking it. The small amounts of coal used before tests were delivered directly to the fireroom and were not taken from the weighed coal in the bunker. During a test an approximately known quantity of coal, measured with a large sheet-iron bucket, was put on the firing floor at a time, the approximate weight and time of delivery being recorded. In this manner the rate of combustion was maintained at the desired rate, and all the weighed coal in the bunker was burned before closing the test. On all tests when a new supply of coal was delivered from the bunker to the firing floor a sample for chemical analysis was taken and put into a covered can. This sample coal was weighed and subtracted from the total coal weighed for the test.

Weight of water fed to boiler.—Water was measured in a tank with a capacity of 2,239 pounds placed on deck above the reserve water tank. The bottom of the measuring tank was funnel-shaped, to permit quick emptying. The top of the tank was contracted by means of a cone into a narrow 8-inch neck in order that when filling the tank any difference of level due to tossing of the boat would introduce only an inappreciable error. From the measuring tank the water was run into the reserve tank and thence was pumped by the auxiliary feed pump into the boiler. Tests were started with the reserve tank full, and during the test the number of measuring tanks emptied and the times of emptying were recorded. At the end of a test any quantity of water left in the measuring tank and not required to fill the reserve tank completely was weighed in a smaller tank

placed on a platform scale and proper correction made of the total water weight.

Feed-water temperature.—A thermometer was immersed in the reserve tank and read at regular intervals.

Flue-gas sampling.—Flue gas was sampled with the specially constructed gas sampler described on page 10–11. The sample was collected on the deck at the stack and then taken to the cabin, where it was analyzed for CO_2, O_2, and CO. The location of the sampler is shown in figure 1.

Flue-gas temperature.—The flue-gas temperature was measured with a platinum and platinum-rhodium thermocouple. The thermocouple was placed in the center of the stack near the flue-gas sampler and was connected with a cord to a galvanometer placed on the dock and reading in degrees Centigrade.

Furnace temperature.—Furnace temperature was measured with a Wanner optical pyrometer. For this purpose a hole 1¼ inches in diameter was drilled in the furnace casing in the back of the boiler and about 3 feet above the grate. This temperature was taken with other readings at regular intervals.

Gas pressures ("drafts").—Gas pressures were measured on all tests at the base of the stack, over the fuel bed, and in the fireroom. For pressures up to 1.5 inches of water above atmosphere the Ellison differential draft gages were used; high pressures were determined with an ordinary U-tube manometer. The gas-pressure gages were placed on the deck and properly piped.

Steam pressures.—Steam pressures were read off a standard gage, which was located on the deck and which was reliable within a pound. The pressures were also automatically recorded by a Crosby recording gage, which was located in the fireroom and which was accurate within 3 pounds.

Moisture in steam.—The moisture in the steam was determined with a throttling calorimeter on the upper end of a ½-inch pipe 30 inches long, which ascended vertically from a short piece of horizontal steam main between the boiler and the throttle valve. It was impossible to get a horizontal piece of piping into the steam main for lack of space; therefore the vertical piece of piping was run up and the calorimeter placed above the deck. The connecting pipe and the calorimeter were well covered with hair felt. The nipple or the part of the pipe fitted into the steam main extended nearly across the main and was perforated with ⅛-inch holes in the usual manner. Readings of the calorimeter were taken at the regular twenty-minute intervals along with other readings.

Smoke.—Observations of smoke were taken fifteen minutes out of every thirty minutes. Individual readings were taken fifteen

seconds apart. The density of smoke was estimated by comparison with Ringelmann's smoke charts. In the tests run at a high rate of combustion there was occasional flaming in the stack, the flame sometimes reaching 10 feet above its top. The flaming was recorded by the smoke observer.

Weight of sparks.—The weight of sparks ejected from the stack was determined with the spark catchers shown in figure 3 and described on pages 11, 13. These spark catchers collected sparks from 0.1 of the total area of the stack, so that by multiplying by 10 the weight of sparks collected the approximate weight of all the sparks ejected from the stack was obtained. The spark receptacles were large enough to hold the sparks collected during the entire test. At the end of the test the receptacles were removed, the sparks weighed and carefully sampled. A sample of about 2 pounds was sent in an air-tight can for chemical analysis.

Chemical analyses.—All chemical analyses of coal, ash, and sparks were made at the chemical laboratory of the technologic branch of the Survey at Pittsburg, Pa., in charge of F. M. Stanton.

OBSERVED DATA AND CALCULATED ITEMS.

EFFECT OF RATE OF COMBUSTION.

THE TABULAR SHOWING.

In all, 21 tests were made, 10 with run-of-mine coal, 3 with large briquets, and 8 with small briquets. It was planned to make four tests with each run-of-mine coal, varying the rate of combustion from 15 to 60 pounds of coal per square foot of grate per hour, and then duplicate each test with briquets, but the fuel supply was insufficient and only three tests could be made. For this reason no test was run with the rate of combustion below 20 pounds per square foot of grate per hour. For the sake of comparison the tests on briquets were made at approximately the same rates of combustion as the tests on the run-of-mine coal of which the respective briquets were made. The averages of the data taken during the test and the calculated results are given in Table 2. The calculated results given in the table were computed according to the method given in Bulletin 325, pages 151–153, being substantially the method recommended by the American Society of Mechanical Engineers.

TABLE 2.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. Biddle, December 6, 1907, to January 27, 1908.*[a]

Test No.	Designation of coal.	Form of fuel.	Date of trial.	Duration (hours).	Average pressures.		"Draft"[b] (inches of water).		
					Barometer (inches of mercury).[c]	Steam above atmosphere (pounds per square inch).	At base of stack.	Over fuel bed.	In ash pit.
1	2	3	4 (1)	5 (2)	6 (3)	7 (11.1)	8 (12)	9 (13)	10 (14)
1	Jamestown 6	Run of mine	1907. Dec. 6	5.25	30	204.5	−0.11	+0.39	+1.23
2	Jamestown 6	Run of mine	Dec. 7	3.33	30	204.0	− .44	+ .98	+2.48
3	Jamestown 6	Run of mine	Dec. 10	7.15	30	199.0	− .10	+ .24	+ .57
4	Jamestown 6	Large briquets	Dec. 12	6.23	30	206.0	− .13	+ .23	+ .54
5	Jamestown 6	Large briquets	Dec. 13	5.10	30	199.0	− .16	+ .39	+ .83
6	Jamestown 6	Large briquets	Dec. 16	4.03	30	200.3	− .21	+ .83	+2.37
7	Jamestown 11	Run of mine	Dec. 18	4.70	30	203.1	− .23	+ .47	+1.13
8	Jamestown 11	Run of mine	Dec. 19	5.98	30	202.3	− .19	+ .34	+ .65
9	Jamestown 11	Run of mine	Dec. 20	4.05	30	202.8	− .51	+1.30	+2.35
10	Jamestown 11	Small briquets	1908. Jan. 3	3.97	30	202.0	− .29	+ .48	+ .97
11	Jamestown 11	Small briquets	Jan. 6	4.08	30	202.0	− .50	+1.45	+2.55
12	Jamestown 11	Small briquets	Jan. 8	6.08	30	207.0	− .17	+ .27	+ .84
13	Jamestown 11	Small briquets	Jan. 10	2.37	30	203.0	− .68	+2.22	+3.39
14	Jamestown 9	Run of mine	Jan. 13	6.78	30	204.1	− .14	+ .36	+ .79
15	Jamestown 9	Run of mine	Jan. 14	4.62	30	203.0	− .33	+ .57	+1.33
16	Jamestown 9	Run of mine	Jan. 17	4.30	30	202.8	− .74	+1.50	+3.95
17	Jamestown 9	Small briquets	Jan. 20	5.30	30	203.9	− .11	+ .27	+ .83
18	Jamestown 9	Small briquets	Jan. 21	4.20	30	205.0	− .29	+ .88	+1.76
19	Jamestown 9	Small briquets	Jan. 23	3.85	30	200.0	− .55	+1.97	+3.73
20	Jamestown 11	....do........	Jan. 25	1.58	30	201.0	− .60	+2.32	+4.92
21	Jamestown 10	Run of mine	Jan. 27	4.10	30	204.0	− .16	+ .77	+1.67

Test No.	Revolutions per minute of fan.	Average temperatures (°F.) of—					Moisture in fuel (per cent).	Fuel (total weight in pounds).			Clinker in ash and refuse (per cent).
		Atmosphere.	Steam.	Feed water in tank.	Gases leaving boiler tubes.	Furnace.		As fired.	Dry.	Ash and refuse.	
1	11 (14.5)	12 (15)	13 (17)	14 (18)	15 (21)	16 (22.1)	17 (26)	18 (25)	19 (27)	20 (28)	21 (29)
1	....	54	380	50	739	2,673	1.64	9,171	9,021	1,423	16.65
2	....	53	380	50	739	2,615	1.50	8,076	7,955	642	41.90
3	312	66	....	51	646	2,367	1.64	8,283	8,147	739	24.90
4	276	44	381	51	681	2,460	1.76	7,771	7,634	707	32.11
5	347	40	378	50	802	....	1.48	8,678	8,550	519	32.18
6	544	57	379	51	919	2,586	1.78	10,778	10,586	615	39.51
7	426	60	380	50	655	2,273	1.92	8,368	8,207	666	21.62
8	324	45	379	50	597	2,347	2.91	7,249	7,038	828	26.40
9	635	49	380	50	728	2,624	2.50	10,941	10,667	605	35.70
10	389	45	379	50	696	2,662	1.26	7,390	7,297	487	34.70
11	626	43	379	49	797	2,921	1.87	10,912	10,708	643	23.48
12	320	49	380	49	583	2,633	1.57	7,313	7,198	617	28.04
13	744	40	379	49	807	3,097	1.79	9,074	8,912	351	15.10
14	357	47	....	49	583	2,502	2.55	8,530	8,312	597	28.81
15	436	42	383	49	668	2,881	2.29	8,224	8,036	481	36.59
16	701	42	383	49	716	....	2.81	13,375	12,999	839	38.74
17	309	55	383	48	637	2,442	1.39	7,464	7,360	485	30.93
18	375	60	384	48	709	2,765	1.71	9,239	9,081	423	45.15
19	382	50	382	50	752	2,950	2.36	11,836	11,557	447	32.89
20	750-800	31	380	45	817	3,070	1.79	6,670	6,551	343	44.02
21	....	44	383	47	601	2,498	2.61	7,098	6,913	432	69.44

[a] Code numbers (in parentheses at the top of certain columns) refer to corresponding items described in Bull. U. S. Geol. Survey No. 325, pp. 151-153.
[b] The word "draft" is placed in quotation marks because it is misused when applied to the moving of gases or to the pressure difference which causes them to move.
[c] Taken as constant.

TABLE 2.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. Biddle, December 6, 1907, to January 27, 1908*—Continued.

Test No.	"Combustible"* [a] consumed (pounds).	Ash and refuse in dry fuel (per cent).	Proximate analysis (per cent). Fixed carbon. In moist coal.	Fixed carbon. In "combustible."	Volatile matter. In moist coal.	Volatile matter. In "combustible."	Moisture. In fuel as fired.	Moisture. Accompanying 100 per cent "combustible."	Ash.	Sulphur (separately determined). Moist basis.	Sulphur. Dry basis.
1	22 (30)	23 (31)	24 (32)	25	26 (33)	27	28 (34)	29	30 (35)	31 (36)	32 (41)
1	7,738	15.77	74.29	79.97	18.61	20.03	1.64	1.77	5.46	0.76	0.77
2	7,167	8.07	73.57	79.97	18.43	20.03	1.50	1.63	6.50	.71	.72
3	7,427	9.07	74.57	79.20	19.58	20.80	1.64	1.74	4.21	.65	.66
4	6,967	9.26	70.75	75.74	22.66	24.26	1.76	1.88	4.83	.90	.92
5	7,864	6.07	70.54	75.32	23.11	24.68	1.48	1.58	4.87	.89	.90
6	9,804	5.81	72.34	77.56	20.93	22.44	1.78	1.91	4.95	.86	.88
7	7,364	8.12	77.54	83.96	14.81	16.04	1.92	2.08	5.73	.70	.71
8	6,243	11.76	74.69	81.98	16.42	18.02	2.91	3.19	5.98	.97	1.00
9	9,694	5.67	74.32	81.89	16.44	18.11	2.50	2.75	6.74	.73	.75
10	6,684	6.67	75.71	81.48	17.21	18.52	1.26	1.36	5.82	.78	.79
11	9,740	6.00	74.21	80.52	17.95	19.48	1.87	2.03	5.97	.80	.82
12	6,529	8.57	75.11	81.16	17.43	18.84	1.57	1.70	5.89	.77	.78
13	8,195	3.94	74.48	80.64	17.88	19.36	1.79	1.94	5.85	.86	.88
14	7,422	7.18	67.46	74.98	22.51	25.02	2.55	2.83	7.48	.61	.63
15	7,291	5.99	68.98	75.81	22.01	24.19	2.29	2.52	6.72	1.01	1.03
16	12,108	6.45	69.24	74.76	23.38	25.24	2.81	3.03	4.57	.42	.43
17	6,843	6.59	69.74	74.63	23.71	25.37	1.39	1.49	5.16	.65	.66
18	8,474	4.66	69.37	74.62	23.60	25.38	1.71	1.84	5.32	.67	.68
19	10,739	3.87	69.44	75.06	23.07	24.94	2.36	2.55	5.13	.66	.68
20	6,054	5.24	69.75	74.98	23.28	25.02	1.79	1.92	5.18	.68	.69
21	6,114	6.25	72.62	82.53	15.37	17.47	2.61	2.97	9.40	.79	.81

Test No.	Ultimate analysis, dry basis (per cent). Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	Carbon in refuse (per cent).	Earthy matter in refuse, including moisture (per cent).	Fired per hour (pounds). Dry fuel. For grate.	Dry fuel. Per square foot of grate.	"Combustible" (*).	Heat value per pound (B. t. u.). Dry fuel.	"Combustible."
1	33 (37)	34 (38)	35 (39)	36 (40)	37 (42)	38 (44)	39 (45)	40 (46)	41 (48)	42 (47)	43 (50)	44 (51)
1	82.58	4.55	5.10	1.45	5.55	54.95	45.05	1,718	29.62	1,474	14,845	15,715
2	83.39	4.49	3.42	1.38	6.60	40.99	59.01	2,389	41.20	2,152	14,591	15,622
3	84.39	4.65	4.63	1.39	4.28	50.22	49.78	1,139	19.64	1,039	15,098	15,773
4	84.98	4.57	3.11	1.50	4.92	41.29	58.71	1,225	21.12	1,118	14,927	15,699
5	84.23	4.61	3.93	1.39	4.94	50.73	49.27	1,676	28.90	1,542	14,879	15,652
6	82.64	4.39	5.87	1.18	5.04	40.44	59.56	2,627	45.29	2,433	14,933	15,726
7	84.38	4.44	3.19	1.44	5.84	54.63	45.37	1,746	30.10	1,567	14,769	15,685
8	83.61	4.29	3.55	1.39	6.16	43.70	56.30	1,177	20.29	1,044	14,720	15,686
9	83.77	4.23	2.86	1.48	6.91	39.00	61.00	2,634	45.41	2,394	14,702	15,793
10	83.21	4.54	4.16	1.41	5.89	37.56	62.44	1,838	31.68	1,684	14,980	15,918
11	84.53	4.37	2.80	1.40	6.08	49.14	50.86	2,625	45.26	2,388	14,816	15,775
12	83.06	4.49	4.32	1.37	5.98	38.61	61.39	1,184	20.41	1,074	14,794	15,735
13	83.69	4.42	3.60	1.45	5.96	53.02	46.98	3,760	64.83	3,458	14,805	15,743
14	80.95	4.73	4.52	1.49	7.68	42.16	57.84	1,226	21.14	1,095	14,368	15,563
15	82.00	4.73	3.86	1.50	6.88	39.88	60.12	1,739	29.98	1,578	14,564	15,640
16	83.95	4.82	4.57	1.53	4.70	33.40	66.60	3,023	52.12	2,816	14,884	15,618
17	84.12	4.72	3.85	1.42	5.23	27.26	72.74	1,389	23.95	1,291	14,949	15,774
18	83.75	4.76	4.03	1.37	5.41	27.26	72.74	2,162	37.28	2,018	14,803	15,650
19	84.05	4.72	3.92	1.38	5.25	47.03	52.97	3,002	51.76	2,789	14,906	15,732
20	84.13	4.65	3.77	1.49	5.27	44.12	55.88	4,146	71.48	3,832	14,796	15,619
21	79.18	4.36	4.69	1.31	9.65	30.43	69.57	1,686	29.07	1,491	14,180	15,695

[a] The "combustible" factor in all columns of this table marked thus (*) is obtained by subtracting from the total weight of dry fuel fired the weight of ash therein, as figured from the chemical analysis, and further subtracting weight of the combustible in the refuse, the latter combustible being calculated from the total weight of refuse and its analysis; the composition of the refuse combustible is loosely considered to be the same as that of the "combustible" of the dry fuel.

TABLE 2.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. Biddle, December 6, 1907, to January 27, 1908*—Continued.

Test No.	Steam.		Water fed to boiler (pounds).						Evaporation.	
	Moisture in (per cent).	Quality of.	Total.	Equivalent evaporated from and at 212°.			Actually evaporated.[a]		Apparent per pound of coal as fired.	Factor of.
				Total.	Per hour.	Into dry steam.	Total.	Per hour.		
1	45 (54)	46 (56)	47 (57)	48 (58)	49 (63)	50 (61)	51 (59)	52 (62)	53 (68)	54 (60)
1	1.10	99.22	68,579	83,989	15,873	83,333	68,044	12,961	7.48	1.2247
2	1.13	99.20	58,940	72,184	21,503	71,606	58,468	17,558	7.30	1.2247
3	1.67	98.81	64,985	79,470	10,983	78,525	64,212	8,981	7.85	1.2229
4	1.73	98.77	59,102	72,335	11,468	71,445	58,375	9,370	7.61	1.2239
5	1.55	98.90	57,483	70,359	13,644	69,586	56,851	11,147	6.62	1.2240
6	1.61	98.86	68,569	83,874	20,575	82,917	67,787	16,821	6.36	1.2232
7	1.57	98.89	59,121	72,400	15,233	71,596	58,465	12,439	7.06	1.2246
8	1.61	98.86	57,811	70,784	11,702	69,977	57,152	9,557	7.98	1.2244
9	1.73	98.77	75,855	92,884	22,652	91,742	74,922	18,499	6.93	1.2245
10	1.90	98.65	55,607	68,085	16,918	67,166	54,856	13,818	7.52	1.2244
11	2.35	98.33	78,415	96,090	23,158	94,484	77,105	18,898	7.19	1.2254
12	1.85	98.69	60,065	73,646	11,954	72,681	59,278	9,750	8.21	1.2261
13	2.42	98.29	57,697	70,708	29,324	69,498	56,710	23,928	6.36	1.2255
14	2.16	98.47	64,975	79,640	11,567	78,422	63,981	9,437	7.62	1.2257
15	1.98	98.60	58,624	71,850	15,334	70,843	57,803	12,511	7.13	1.2256
16	2.25	98.41	88,247	108,147	24,750	106,427	86,844	20,196	6.60	1.2255
17	1.68	98.81	54,875	67,315	12,550	66,514	54,222	10,231	7.35	1.2267
18	1.71	98.83	65,493	80,347	18,906	79,407	64,727	15,411	7.09	1.2268
19	2.32	98.40	82,503	100,992	25,812	99,376	81,183	21,086	6.97	1.2241
20	2.51	98.23	41,270	50,741	31,547	49,844	40,540	25,658	6.19	1.2295
21	2.56	98.19	51,075	62,710	15,018	61,575	50,151	12,232	7.20	1.2278

Test No.	Equivalent evaporation per pound of—			Horsepower developed.		Efficiency of the boiler, etc.		Per cent smoke.	Average thickness of fuel bed (inches).[c]
	Fuel as fired.	Dry fuel fired.	"Combustible" (*).	In boiler.	Per cent of builders' rated.[b]	(*)	Including grate.		
1	55 (69)	56 (70)	57 (71)	58 (65)	59 (67)	60 (72)	61 (73)	62 (77)	63 (81)
1	9.09	9.24	10.77	460.1	166	66.17	60.11	64.50	12
2	8.87	9.00	9.99	623.3	225	61.75	59.57	60.89	14
3	9.48	9.64	10.57	318.3	115	64.71	61.66	58.75	8
4	9.19	9.36	10.25	332.4	120	63.05	60.55	69.54	16
5	8.02	8.14	8.85	395.5	143	54.60	52.83	70.54	16
6	7.69	7.83	8.46	596.4	215	51.95	50.64	67.20	6
7	8.56	8.72	9.72	441.5	159	59.84	57.02	29.88	10
8	9.65	9.94	11.21	339.2	122	69.01	65.21	35.87	8
9	8.39	8.61	9.46	656.6	236	57.85	56.56	30.57	16
10	9.09	9.20	10.05	490.4	177	60.97	59.31	48.75	8
11	8.66	8.82	9.70	671.3	242	59.38	57.49	37.86	10
12	9.94	10.10	11.13	346.5	125	68.31	65.93	31.02	8
13	7.66	7.80	8.48	850.0	306	52.02	50.88	37.81	10-12
14	9.19	9.43	10.57	335.3	121	65.58	63.38	47.41	8
15	8.61	8.82	9.72	444.5	160	60.02	58.48	48.84	10
16	7.96	8.19	8.79	717.4	254	54.35	53.14	43.03	12
17	8.91	9.04	9.72	363.8	131	59.51	58.39	46.14	8-9
18	8.59	8.74	9.37	548.1	197	57.82	57.02	49.28	8-9
19	8.40	8.60	9.25	748.2	270	56.78	55.72	21.71	10-12
20	7.47	7.61	8.23	914.4	330	50.89	49.67	51.33	12
21	8.67	8.91	10.07	435.3	157	61.96	60.68	31.86	10

[a] Corrected for quality of steam.
[b] Arbitrarily rated, counting 10 square feet of heating surface to a boiler horsepower.
[c] Method of firing, side alternate.

TABLE 2.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. Biddle, December 6, 1907, to January 27, 1908*—Continued.

Test No.	Analysis of dry flue gases (per cent).				Pounds of dry flue gases per pound of "combustible."	Sparks ejected (pounds).		Heat Value of 1 pound of "combustible" (B. t. u.).	Heat balance.[a]			
	CO_2.	O_2.	CO.	N_2.		During test.	Per hour.		Heat absorbed by boiler (1).		Heat lost in dry flue gases (4).	
									B. t. u.	Pr. ct.	B. t. u.	Pr. ct.
1	64 (84)	65 (85)	66 (86)	67 (88)	68	69	70	71	72	73	74	75
1	7.90	10.53	0.12	81.45	26.97	200	38.2	15,717	10,401	66.17	4,342	27.63
2	9.06	9.60	.08	81.26	24.28	412	123.7	15,622	9,647	61.75	3,933	25.18
3	9.27	9.44	.03	81.26	23.59	125	17.0	15,773	10,207	64.71	3,199	20.28
4	10.52	7.30	.14	82.04	20.94	35	5.6	15,699	9,898	63.05	3,087	19.66
5	11.70	5.03	.00	83.27	18.98	265	52.0	15,652	8,546	54.60	3,371	21.54
6	12.41	4.64	.00	82.95	17.63	230	57.0	15,726	8,170	51.95	3,600	22.89
7	9.86	8.22	.00	81.92	22.65	......	......	15,685	9,387	59.84	3,289	20.97
8	9.16	9.30	.00	81.54	24.18	......	......	15,686	10,825	69.01	3,111	19.83
9	10.27	7.95	.00	81.78	21.88	......	......	15,793	9,136	57.85	3,497	22.14
10	10.37	7.65	.02	81.96	21.25	......	......	15,918	9,705	60.97	3,233	20.31
11	10.40	7.40	.00	82.20	21.60	400	97.0	15,775	9,367	59.38	3,841	24.35
12	9.50	9.13	.00	81.37	23.15	80	13.2	15,735	10,748	68.31	2,879	18.30
13	11.86	5.53	.00	82.61	18.83	380	160.0	15,743	8,189	52.02	3,426	21.76
14	10.00	8.40	.00	81.60	21.87	180	26.5	15,563	10,207	65.58	2,714	17.44
15	10.97	7.00	.00	82.03	20.09	210	45.5	15,640	9,387	60.02	2,951	18.87
16	9.85	8.07	.00	82.08	22.28	410	95.0	15,618	8,489	54.35	3,529	22.60
17	9.58	8.20	.00	82.22	23.06	60	11.3	15,774	9,387	59.51	3,121	19.79
18	9.60	8.10	.00	82.30	22.95	240	57.0	15,650	9,049	57.82	3,503	22.38
19	9.36	8.12	.00	82.52	....	440	114.0	15,732	8,933	56.78	3,906	24.83
20	10.30	6.85	.00	82.85	21.50	380	240.0	15,619	7,948	50.89	3,988	25.53
21	10.40	7.47	.00	82.13	21.04	180	44.0	15,695	9,725	61.96	27.67	17.62

Test No.	Heat balance.[a]										Smoke and flame showing above stack.		
	Loss due to moisture—				Loss due to incomplete combustion of carbon in CO (5).		Loss in sparks.		Loss in escaping hydrocarbons, radiation, and unaccounted for (6).		F.	S.	Per cent.[b]
	In fuel (2).		Formed by burning hydrogen (3).										
	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.			
1	76	77	78	79	80	81	82	83	84	85	86	87	88
1	24	0.15	591	3.76	133	0.85	307	1.96	−81	−0.52	0	608	0.0
2	22	.14	592	3.80	79	.50	648	4.15	703	4.50	7	360	2.0
3	23	.15	571	3.62	29	.18	186	1.18	1,558	9.88	1	720	.1
4	25	.16	578	3.68	119	.76	51	.32	1,941	12.37	6	660	.9
5	22	.14	611	3.90	0	....	348	2.22	2,751	17.60	65	480	13.5
6	28	.18	602	3.83	0	....	248	1.58	3,078	19.57	214	508	42.8
7	28	.18	569	3.63	0	....	....	....	2,412	15.38	13	480	2.7
8	42	.27	536	3.42	0	....	....	....	1,172	7.47	0	664	.0
9	37	.23	557	3.53	0	....	....	....	2,566	16.25	6	452	1.3
10	18	.11	585	3.68	17	.11	....	....	2,360	14.82	19	480	4.0
11	28	.18	587	3.72	0	....	389	2.46	1,563	9.91	24	420	5.7
12	22	.14	555	3.52	0	....	113	.72	1,418	9.01	0	686	.0
13	27	.17	598	3.80	0	....	470	2.99	3,033	19.26	59	292	20.2
14	37	.24	594	3.82	0	....	266	1.71	1,745	11.21	1	764	.1
15	34	.22	613	3.92	0	....	295	1.89	2,360	15.08	7	500	1.4
16	41	.26	621	3.98	0	....	369	2.36	2,569	16.45	9	456	2.0
17	19	.12	587	3.72	0	....	87	.55	2,573	16.31	16	600	2.7
18	25	.16	608	3.89	0	....	314	2.01	2,151	13.74	8	420	1.9
19	35	.22	617	3.92	0	....	443	2.82	1,798	11.43	13	420	3.1
20	27	.17	629	4.03	0	....	744	4.76	2,283	14.62	14	240	5.8
21	39	.25	569	3.63	0	....	323	2.06	2,474	14.48	1	420	.2

[a] Heat balance items (designated by numbers in parentheses under this heading) are explained in Bull. U. S. Geol. Survey No. 325, p. 153.

[b] Per cent $= \frac{\text{Flame readings}}{\text{Smoke readings}} \times 100$.

NOTES ON INDIVIDUAL TESTS.

Test 1, J-6 coal, run-of-mine.—Coal caked badly. Fuel bed required much attention; the cakes had to be broken about every other firing. During the test the fuel bed was 12 to 14 inches thick.

It was impracticable to clean fire before closing test. After test was closed and the fuel bed had entirely burned down the clinkers were removed from the grate, weighed, and charged to the test. All ashes were then taken out of the ash pan, weighed, and charged to the test. It is possible that the weight of ash on this test is too high, because, when removing the clinkers from the grate, some free ash which really did not belong to the test fell into the ash pan and was weighed with the rest.

Test 2, J-6 coal, run-of-mine.—Coal caked badly; fires had to be raked after each firing. The fact that the fire doors had to be partly open while raking the fire possibly accounts for the high oxygen content in the flue-gas analysis. It was difficult to keep the fuel bed in good condition.

The fire was not cleaned before closing the test. After the test was closed, all the ashes were pulled out of the ash pan, weighed, and charged to the test. Then, after the fuel bed had entirely burned down, the clinkers were removed from the grate, weighed, and charged to the test. The firing was better on this test than on test 1; less coal was allowed to fall through the grate.

Test 3, J-6 coal, run-of-mine.—Coal caked badly; it was necessary to break the cakes after every other firing. After closing the test the free ash was pulled out of the ash pan and weighed. Then, after the fire had entirely burned down, the clinkers were pulled out of the furnace, weighed, and charged to the test. The free ash which fell through the grate during the process of pulling clinkers was not charged to the test, as there was about an equal quantity of ash on the grate when the test was started. This method of determining ash and clinkers was used for all the following tests.

Test 4, J-6 coal in large briquets.—Briquets burned freely and quickly and stayed together in the fire. Fire handled easily. Thickness of fire during test, 12 to 14 inches.

Test 5, J-6 coal in large briquets.—Briquets burned freely and quickly and stayed together in the fire. The fire was easily handled. Thickness of fire, 14 to 16 inches.

Test 6, J-6 coal in large briquets.—Briquets burned freely and quickly and did not crumble in the fire. The fire was apparently in good condition during the entire test. Thickness of fire, 14 to 16 inches. Excessive flaming in the stack was observed.

Test 7, J-11 coal, run-of-mine.—Coal caked badly; fire required raking after every other firing. About 100 pounds of coal fired at a time, alternately on each side half of the grate every three or four minutes. Thickness of fire, 10 to 12 inches. Water was used in the ash pan during the test.

Test 8, J-11 coal, run-of-mine.—Coal caked badly; fire required breaking up every other firing. About 75 to 100 pounds of coal fired at a time, alternately on each side half of the grate every four or five minutes. Thickness of the fuel bed, about 8 inches. Water was used in the ash pan.

Test 9, J-11 coal, run-of-mine.—Coal caked badly. It was necessary to break up the cakes after every other firing. About 100 pounds of coal was charged alternately on each side half of the grate every two or three minutes. Thickness of fuel bed, about 14 to 16 inches. Water was used in the ash pan during the test.

Throughout this test much fuel was blown out through the stack in the form of cinders or sparks. At the close of the test the deck was covered with a layer of sparks varying from one-eighth to three-eighths of an inch thick.

Test 10, J-11 coal in small briquets.— Briquets burned freely; stayed together in the fire. About 100 pounds were charged alternately on each side half of the grate every three or four minutes. Fire handled easily and did not require much attention. Thickness of the fuel bed, about 8 inches. Water was used in the ash pan.

Test 11, J-11 coal in small briquets.—Briquets burned freely; stayed together in the fire. About 100 pounds were fired alternately on each side half of the grate every two or three minutes. Fire handled easily. Effort was made to keep the fuel bed 8 to 10 inches thick. Better results seemed to have been obtained with a light fire than with a heavy one. Water was used in the ash pan.

Test 12, J-11 coal in small briquets.—Briquets burned freely; did not crumble in the fire. About 100 pounds charged alternately on one-half of the grate every five or six minutes. Fire handled easily. Thickness of fuel bed, about 6 inches. Water was used in the ash pan.

Test 13, J-11 coal in small briquets.—Briquets burned freely and made a very hot fire. About 130 pounds charged alternately on each side half about every one or two minutes. The fuel bed was easily handled. Thickness, about 10 to 12 inches. Water was used in the ash pan.

Test 14, J-9 coal, run-of-mine.—Coal caked badly. Fire had to be raked after every other firing. About 300 pounds was charged alternately on each side half of the grate every four or five minutes. Thickness of fuel bed, about 8 inches. Water was used in the ash pan.

Test 15, J-9 coal, run-of-mine.—This coal was exceptionally bad in regard to caking. The fuel bed had to be raked every other firing and sliced about every fourth or fifth firing in order to keep it loose. About 300 pounds was charged alternately on each side half of the grate every two or three minutes. Thickness of fuel bed, about 10 inches. Water was used in the ash pan.

Test 16, J-9 coal, run-of-mine.—Coal caked considerably. Fuel bed had to be raked after every other firing. About 150 pounds fired alternately on each side half of the grate every three or four minutes. Thickness of fire, about 12 inches. Water was used in the ash pan. During the latter part of this test the screens in the spark catchers were burned out so as to catch only about three-fourths of the full tenth of the sparks.

Test 17, J-9 coal in small briquets.—The briquets swelled in the fire, and their surfaces opened cracks in many places, but did not crumble unless broken with a rake. About 75 pounds charged alternately on each side half of the grate every three or four minutes. These briquets burned best in this furnace at this rate of combustion, with about an 8-inch fuel bed. When the fuel bed was thickened the gases flamed in the stack.

Test 18, J-9 coal in small briquets.—About 120 pounds fired alternately on each side half about every three minutes. These briquets burned best at this rate of combustion, with about an 8 to 10 inch fuel bed. When the bed was thicker, gases flamed in the stack. Water was used in the ash pan.

Test 19, J-9 coal in small briquets.—Briquets swelled in the fire, but did not crumble. About 120 pounds fired alternately one each side half of the grate about every two minutes. To avoid flaming the stack, the fuel bed could not be made thicker than 12 inches.

Test 20, J-11 coal in small briquets.—About 10 per cent of the briquets were crumbled when fired. This test was short on account of shortage of fuel. After it was well under way the rate of combustion was much higher than the average given in the table. The method of firing used was side alternate, as in the previous tests. Thickness of fuel bed, about 12 inches; when thicker, flaming began in the stack. A higher rate of combustion and capacity of boiler could have been obtained with these briquets if more fuel had been available, and even higher rates would be obtainable by running the fan faster, as it well could be.

Test 21, J-10 coal, run-of-mine.—Coal caked badly, making it necessary to rake the fuel bed after every other firing. Method of firing, side alternate, as in all the prior tests. Thickness of fire, about 10 inches.

DATA AND CALCULATIONS SHOWN GRAPHICALLY.

EXPLANATION OF FIGURES.

Figures 4 to 10, inclusive, show graphically the relations of the results of the tests to the rate at which coal was burned. The abscissas are pounds of dry coal fired per square foot of grate per hour; the ordinates are various quantities and are given directly at the left of each group of curves or group of points. All points are for individual tests; trials on large briquets are denoted by solid rectangles, those on small briquets by dots, and those on run-of-mine coal by light circles. Where it was possible to discriminate between the kinds of fuel solid heavy lines were drawn through points representing the results on coal, long dash lines through points representing results on large briquets, and short dash lines through points representing tests on small briquets.

ON CAPACITY DEVELOPED.

The points shown in succession at the top of figure 4 represent the relation between the rate of combustion and the capacity developed by the boiler. In order to have a basis of comparison between these tests and tests made on other boilers the rated capacity of the Normand boiler of the *Biddle* was assumed as 277.6 boiler horsepower; that is, 10 square feet of heating surface is taken to be equivalent to 1 boiler horsepower. All the points of this group fall so nearly along one straight line that it is hard to tell whether the run-of-mine coal or the briquets did better. The shape and the inclination of the curve passing through these points indicate that the capacity increases almost directly with the rate of combustion; this fact is perhaps self-evident—the greater the amount of coal burned the greater the amount of heat generated in the furnace and the greater the amount of heat absorbed by the boiler. It is worthy of note that on all the tests this particular boiler with its heating surface developed two or three times as much boiler horsepower as stationary boilers ordinarily do. This indicates that the rule of thumb which states that 10 square feet of heating surface are required to give 1 boiler horsepower has no substantial foundation.

ON EVAPORATION.

The points in the middle group of figure 4 show the relation between rate of combustion and evaporation per pound of dry fuel fired, and indicate that the run-of-mine coal and the small briquets do about equally well, the briquets probably giving a very slightly better evaporation than the coal. The large briquets fall considerably lower in evaporation than the other two fuels. This lower evaporation, however, was not caused by the inferiority of the

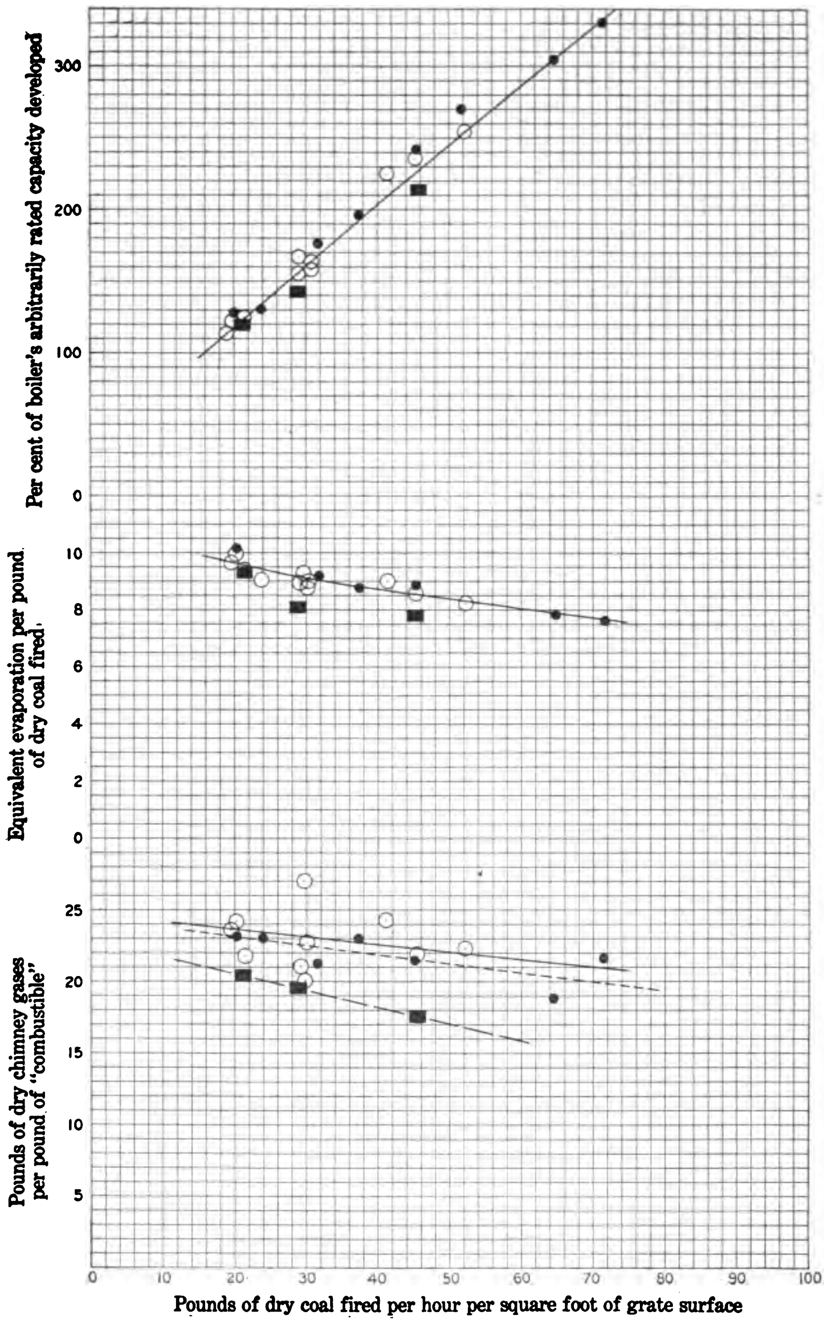


FIGURE 4.—Effect of increasing rate of combustion on (1) percentage of boiler's arbitrarily rated horsepower developed; (2) equivalent evaporation per pound of dry coal fired; and (3) pounds of dry chimney gases per pound of "combustible."

briquets as a fuel, but was due to the fact that the fuel beds carried on these tests were too thick, and the resulting insufficient air supply caused incomplete combustion. Although the flue-gas analyses on these tests show a very low CO percentage, the presence of flames in and above the stack indicated that combustible gases other than CO were escaping. It was thought, because the voids in the fuel bed of large briquets were higher in percentage than with the other fuels, that better results could be obtained with the thicker fuel beds. This reasoning, however, proved false, at least with the particular briquets tested.

A general curve drawn through these points indicates that the evaporation per pound of dry coal drops considerably as the rate of combustion increases. Thus at the rate of 20 pounds the equivalent evaporation per pound of dry coal is a little above 10 pounds, while at the rate of 71 pounds the equivalent evaporation is less than 8 pounds of water. This drop in evaporation when the rate of combustion increases is chiefly due to less complete combustion of the fuel; it will be shown later that only a little of it is due to the inability of the boiler proper to absorb the heat.

ON DRY FLUE GASES.

The points in the lowest group of figure 4 show the relation between the rate of combustion and the weight of dry flue gases per pound of "combustible" [a] ascending from the grate.

In general, the points indicate that with all three kinds of fuel the weight of air used to burn 1 pound of "combustible" decreases as the rate of combustion increases. This feature is well worthy of note in the respect that the higher the gas-pressure drop through the fuel bed (the resistance of the latter remaining about the same) the higher is the velocity of air passing through the burning fuel and the higher is the rate of combustion; now, the dropping of the points at the right hand tells us that the combustion more than keeps up with the velocity of the current of air through the fuel bed. This statement is true throughout the full range of rate of combustion ordinarily used in practice.

The points also show that on the average about the same weight of air is used to burn 1 pound of "combustible" whether the fuel be run-of-mine coal or small briquets. With the large briquets the weight of air used was much less. This fact undoubtedly accounts for the less perfect combustion and lower evaporation on tests with large briquets.

[a] The combustible here referred to is the "combustible" in the fuel as fired, figured from chemical analysis minus the combustible lost in ash and refuse, but including the combustible ejected in sparks. In this bulletin the word combustible is placed in quotation marks whenever it is loosely used in the sense of "coal free from moisture and ash."

ON SMOKE.

The points in the lower group of figure 5, that is, the points which are connected by broken lines, are intended to show the relation between the per cent of black smoke and the rate of combustion. Each point in the figure represents the average of the whole test. The percentage of black smoke refers to Ringelmann smoke charts; chart 1 is called 20 per cent black smoke, and each successive chart is 20 per cent higher, so that chart 5 is 100 per cent black. Fractional gradations are similarly interpreted within the respective 20 per cent steps.

The lines connecting the points of each kind of fuel fall in such a zigzag fashion that there does not seem to be any relation between the blackness of smoke and the rate of combustion. The most reasonable conclusion probably is that the combustion space of the furnace is so small and the "cold" heating surface of the boiler is so near the fuel that even the rate of combustion of 20 pounds of fuel per square foot of grate is too high to burn the gases and tarry vapors so that the smoke-producing property of the furnace apparently can not be made any worse by increasing further the rate of combustion. The smoke-producing property of this furnace lies in the fact that the path of the gases from the fuel bed into the nests of the water tubes is so short that the tar vapors which are important constituents of visible smoke have not sufficient time to burn before they are driven among the tubes where the combustion stops. As all these visible tars are in liquid or solid form their complete combustion requires considerably more time than is afforded to them on their way from the fuel bed to the nests of tubes. It seems then that no amount of care taken in firing smoky fuels in this type of furnace will produce smokeless combustion.

The points of the same group show that the tendency of a coal to smoke is not reduced by briquetting the fuel; in fact it is shown that rather more smoke was made with briquetted than with run-of-mine coal. The high percentage of black smoke made with the large briquets is partly due to a smaller supply of air, as is shown by the lowest group of points in figure 4.

The points of the upper group of figure 5 show the amount of flaming observed above the stack. Every time the smoke observer read smoke he also made a note of flaming above the stack when the same was observable. The upper ordinate of figure 5 represents the number of times flame was observed above the stack expressed as a percentage of total smoke readings. It is shown that there was more flaming with either style of briquet than with run-of-mine coal.

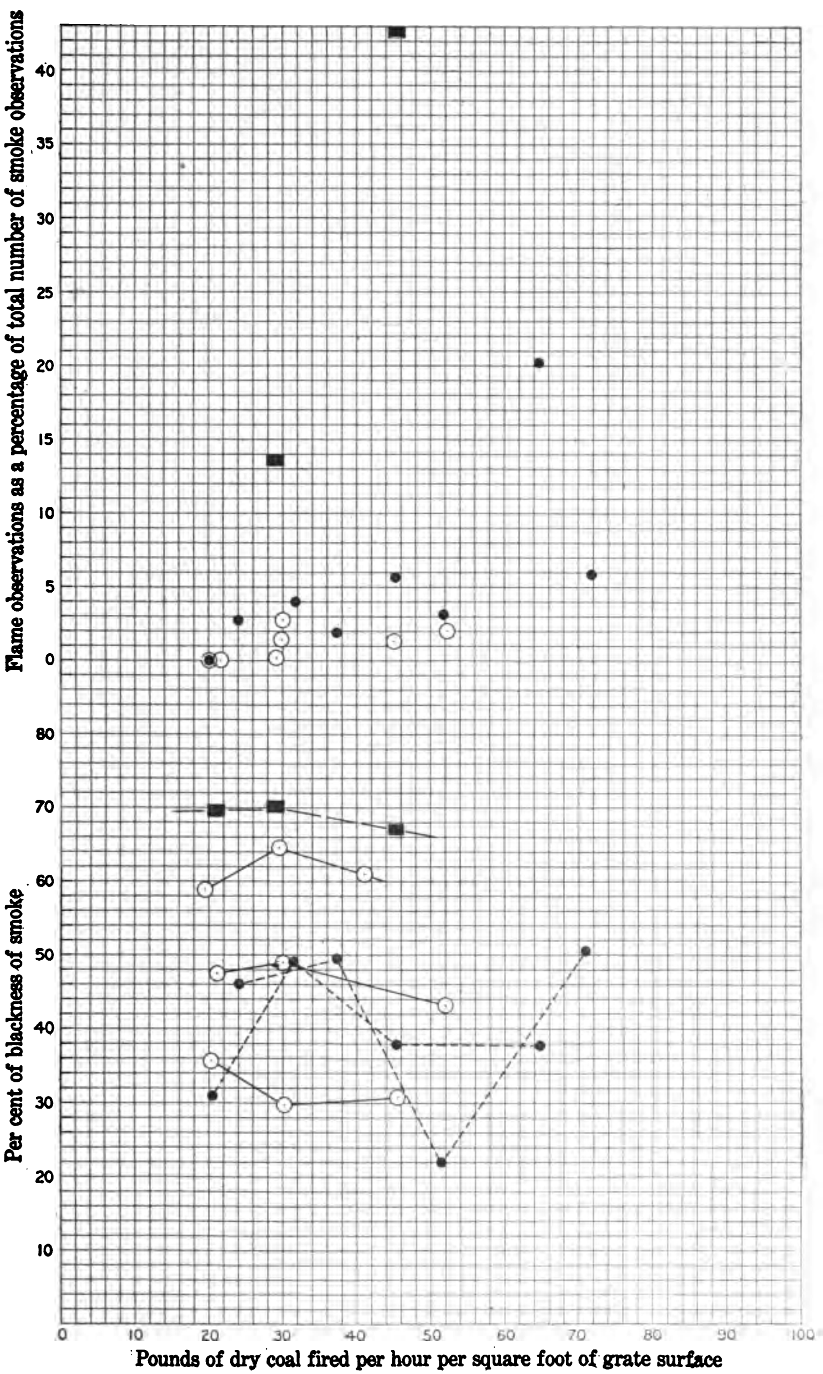


FIGURE 5.—Effect of increasing rate of combustion on flame observations as a percentage of total number of smoke observations (above) and percentage of black smoke (below).

ON DISTRIBUTION OF HEAT.

Figure 6 and the two lower groups of points of figure 7 show how the distribution of the heat of the "combustible" ascending from the grate varied with the rate of combustion. All heat quantities in these two figures are expressed in percentage of the total heat in "combustible" ascending from grate.

ON HEAT LOSSES.

The points grouped at the top of figure 6 represent the heat carried up the stack in the moisture formed by burning of hydrogen and also in the free moisture in the coal (item 2 + item 3 in the heat balance). The points show that the heat loss due to moisture in the flue gases is very nearly the same for all rates of combustion. There is also little or no difference between the three kinds of fuel.

The points of the middle group of figure 6 show the relation of the heat lost in dry flue gases (item 4 in the heat balance) and the rate of combustion. In general, the points show that this heat loss increases but little with the rate of combustion. On the average this increase is 4 to 5 per cent as the rate of burning the fuel increases from 20 to 70 pounds. This item does not show any essential difference between the three kinds of fuel.

The points in the lowest group of figure 6 show the relation of the heat loss in sparks to the rate of combustion. The indication is that this loss increases almost directly with the rate of combustion. The points also show somewhat higher losses in sparks in the tests of run-of-mine coal than of the small briquets. There are not enough tests on large briquets to warrant definite conclusions regarding the spark losses. The higher spark loss shown in tests with run-of-mine coal was undoubtedly due to the high percentage of slack in the coal and also to the fact that the fuel bed had to be frequently stirred. The stirring of the fuel bed loosened small particles of burning fuel which were apt to be carried out through the boiler and stack by the current of gas. The higher spark loss with increasing rate of combustion resulted from higher pressure drops ("drafts") and higher velocities of the furnace gases which had to be maintained in order to effect the higher rates of combustion.

ON HEAT ABSORPTION.

The points in the middle group of figure 7 show the relation of the rate of combustion to the heat absorbed by boiler (item 1 in heat balance). As stated before, this heat is expressed as a percentage of the total heat of the "combustible" ascending from the grate; in other words, this item is the ratio of the two heats multiplied by 100. Generally this ratio is called the "*efficiency of the boiler,*" and is so

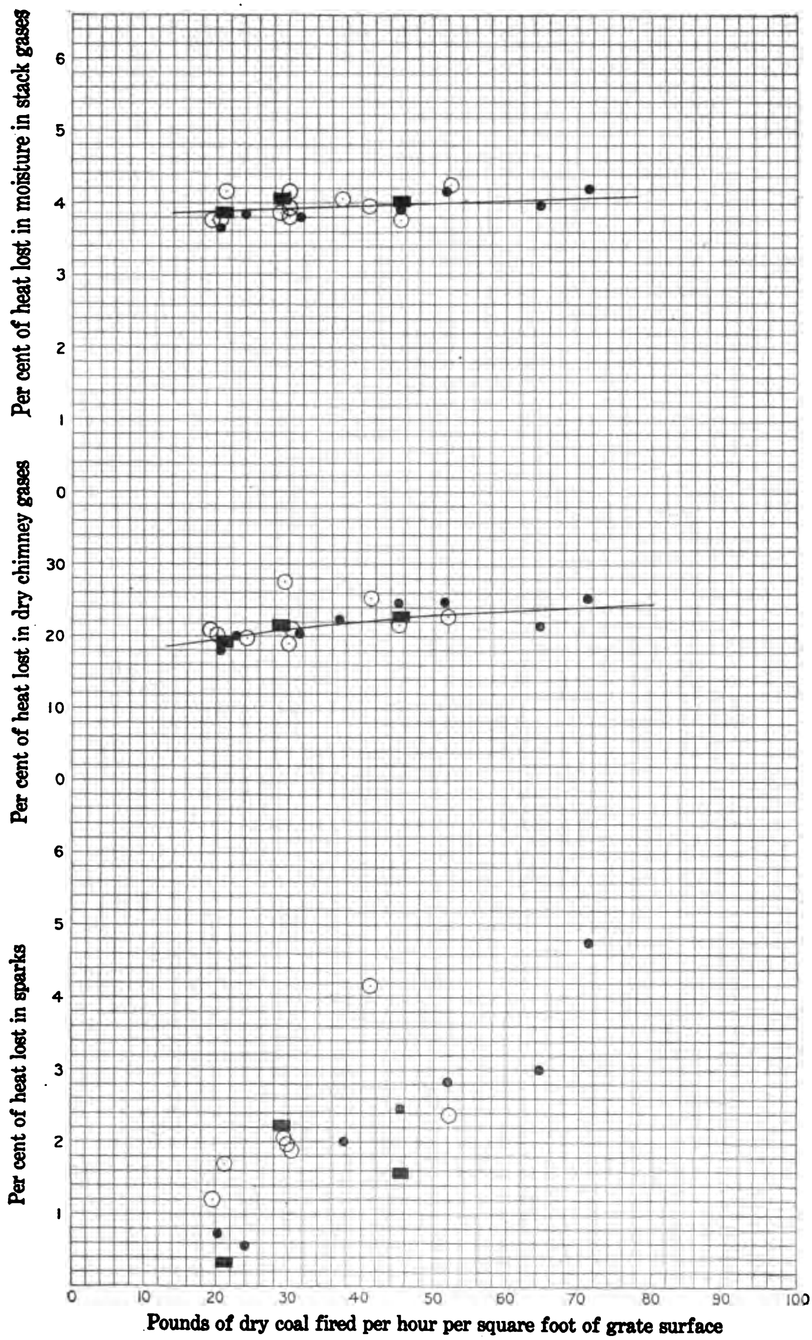


FIGURE 6.—Effect of increasing rate of combustion on (1) percentage of heat lost in moisture in stack gases; (2) percentage of heat lost in dry chimney gases; and (3) percentage of heat lost in sparks.

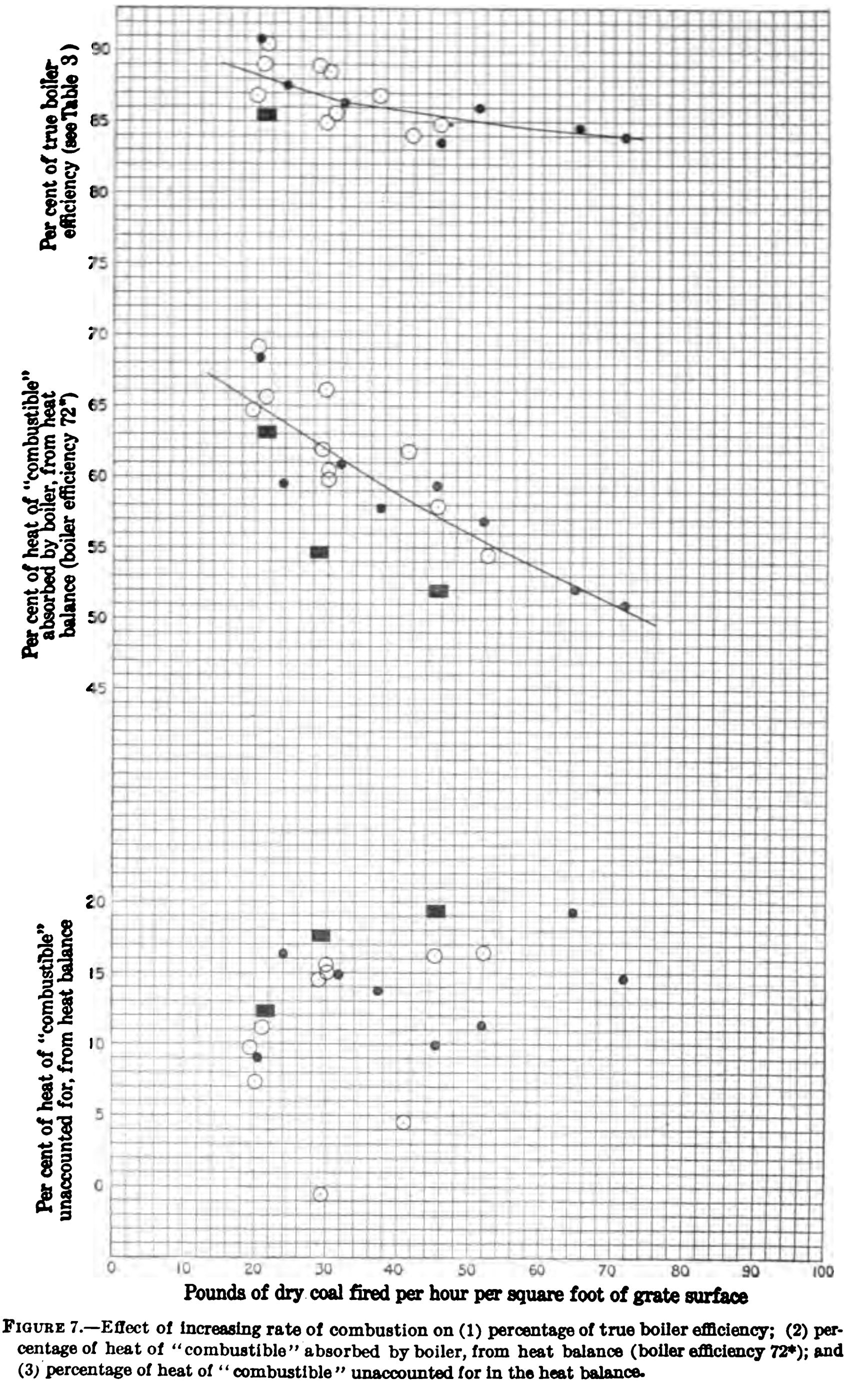


FIGURE 7.—Effect of increasing rate of combustion on (1) percentage of true boiler efficiency; (2) percentage of heat of "combustible" absorbed by boiler, from heat balance (boiler efficiency 72*); and (3) percentage of heat of "combustible" unaccounted for in the heat balance.

denoted by the code of the American Society of Mechanical Engineers, where it is defined as "the heat absorbed by the boiler per pound of combustible divided by the heat of 1 pound of combustible."

The indication of the points is that as the rate of combustion increases the boiler absorbs a considerably smaller percentage of the total heat of the "combustible" ascending from the grate. This apparently large decrease in the boiler efficiency is, however, rather the fault of the furnace as a heat generator than of the boiler as a heat absorber; in other words, it is mainly due to the drop in furnace efficiency. As the rate of firing coal increases, the volume of gases generated in the fuel bed per unit of time increases in the same ratio. The result is that this increasing volume of gases must pass through the combustion space of the furnace at a higher velocity, and therefore a proportionately shorter time is afforded for burning any combustible gases or tar vapors contained in the furnace gases. As a result of this shortened time the combustible gases and tars are only partly burned. Thus, as the rate of firing coal increases, the combustion becomes more and more incomplete.

The potential heat of the combustible gases and tars leaving the furnace and passing out through the boiler and stack is not liberated and therefore is not available for absorption by the boiler. Liberation of heat from fuel is the function of a furnace, and therefore any drop in "boiler efficiency," as the term is commonly used, caused by failure of the furnace to liberate all the heat of the fuel, is directly chargeable to the furnace.

ON UNACCOUNTED-FOR LOSSES.

The determination of the tars and the combustible gases, other than CO, escaping from the furnace is extremely difficult, so that the incompleteness of combustion ordinarily can be estimated only by an indirect method. The usual method is that employed in making a heat balance such as is presented for these tests in columns 72–85, of Table 2. In this heat balance all the losses are accounted for except the radiation loss, the loss due to incomplete combustion of hydrocarbon gases and tars, and a few other minor losses. The remainder of the heat not accounted for (commonly called the "unaccounted for") is principally the loss due to radiation and to incompleteness of combustion. Unfortunately all the errors of observations, of sampling, and of chemical determinations are accumulated in the "unaccounted for," so that the losses by radiation and by incomplete combustion can be only roughly estimated by taking all the possibilities of error into consideration.

The points in the lowest group of figure 7 have been plotted to show the relation between the "unaccounted for" in the heat balance and the rate of combustion. For reasons previously given, the points do not fall along a single line. The two lowest points in the

figure represent the first two tests made in which the flue-gas analysis is unreliable because of leaky joints in the gas-sampling device. On account of this leak the weight of air used to burn 1 pound of "combustible," calculated from the gas analysis, is too high, and consequently the loss up the stack unduly high, leaving the unaccounted-for loss either too low or negative. This illustrates how errors in data affect this item.

The general indication of this group of points is that the unaccounted-for loss increases with the rate of combustion. The radiation loss depends on the temperature of the radiating surfaces of the boiler and therefore should rather decrease in percentage with the increasing capacity accompanying the increased rate of combustion. The increasing unaccounted-for loss when the rate of combustion increases may then be rightly ascribed to the increasing incompleteness of combustion. This fact supports the conclusion arrived at in discussing the middle group of points of the same figure, namely, that the drop in the percentage of heat absorbed by the boiler is mostly due to incomplete combustion of tar vapors and combustible gas other than CO.

ON RUN-OF-MINE COAL AND BRIQUETS.

Referring again to the middle group of points of figure 7, and considering the three kinds of fuel, it is plain that as far as efficiency of the steam-generating apparatus is concerned, there is no advantage in briquetting the fuel. The run-of-mine coal does as well as the small briquets and perhaps better than the large ones. However, any deductions in regard to the efficiency of large briquets must necessarily be reserved until more tests have been made with them. The three tests herein reported were run under rather unfavorable conditions for the good combustion of these briquets. It has been already said that in an attempt to reduce the amount of excess air used in combustion, for the purpose of obtaining high furnace temperature, the latter being one of the requisites for high economy, the fuel bed was carried somewhat too thick (14 to 16 inches). This thickening of the fuel bed and the resulting reduction of air supply very likely caused so much incomplete combustion that the over-all efficiency dropped considerably. Subsequent tests disclosed the fact that in this particular furnace it is not well to increase the CO_2 in the flue gases over 10 or 11 per cent, inasmuch as the combustion space above the fuel bed is too small. This deduction applies to Now River coals; for Pocahontas coal it would probably have to be somewhat modified.

ON FLUE-GAS AND FURNACE TEMPERATURES.

In figure 8 the points of the highest group are the averages of furnace temperatures for each test; the points in the middle group are the averages of flue-gas temperatures for each test; both are platted

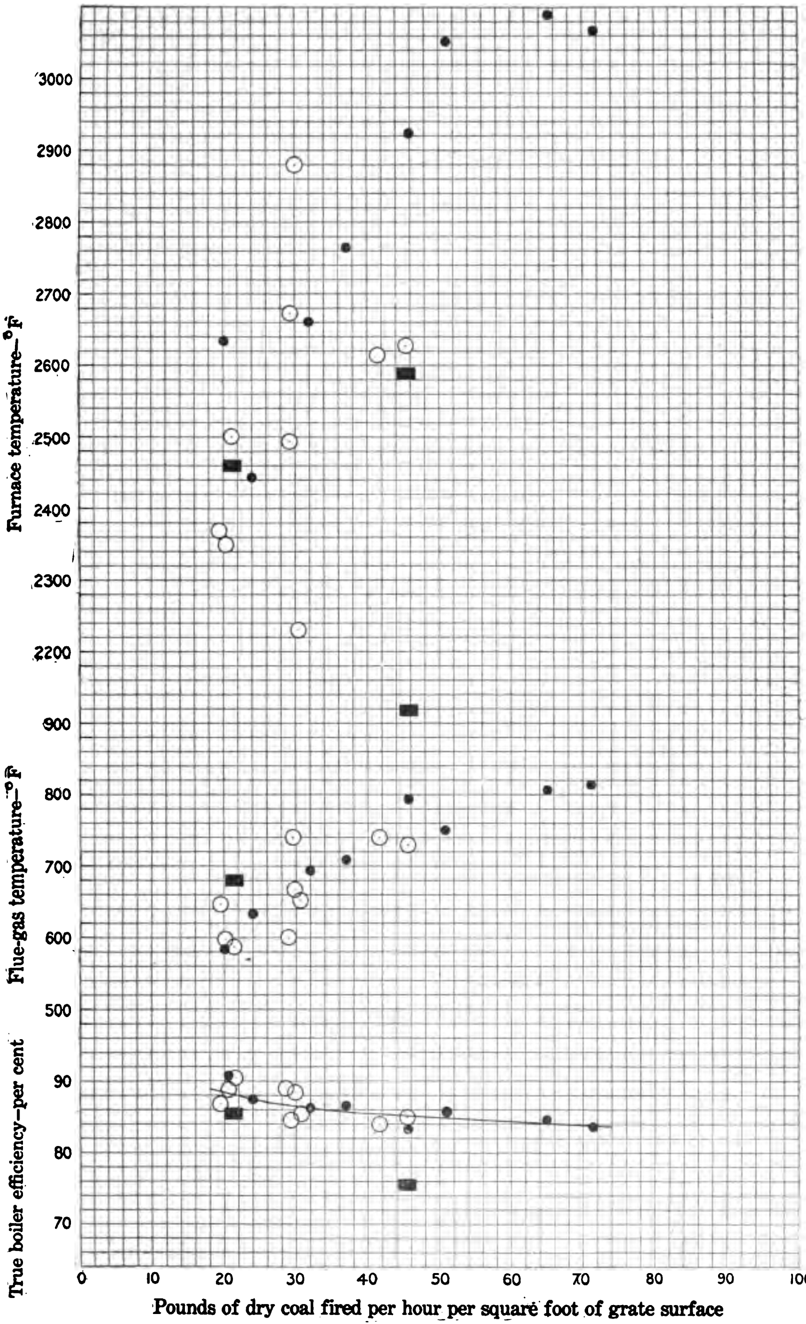


FIGURE 8.—Relation between rate of combustion and (1) furnace temperature in degrees Fahrenheit; (2) flue-gas temperature in degrees Fahrenheit; and (3) true boiler efficiency in percentage.

with the rate of combustion as abscissas. In general, both temperatures seem to rise with the rate of combustion; however, this rising may be an incidental feature whose portrayal was not the object of platting the temperatures. The object of platting was to show a peculiar relation between the two temperatures, which relation seems to be but little affected by the rate of combustion. The furnace temperature here platted is the temperature of the furnace gases as they enter the boiler. The flue-gas temperature is the temperature of the gases as they leave the heating surface of the boiler. The difference between the two is the drop in temperature of these gases due to the absorption of heat from them by the boiler. As the weight of gases entering the boiler and the weight of gases leaving the boiler is the same (neglecting leakage), the temperature drop of the gas is proportional to the heat absorbed by the boiler. In this reasoning it is assumed that the specific heat of furnace gases at constant pressure remains constant, which is not strictly true. Recent experiments show that the specific heat of CO_2 and other gases increases appreciably with temperature. However, as the consideration of the small variations in the specific heats of furnace gases would change the final results only by a fraction of a per cent, it was thought best not to complicate the course of reasoning by considering the variations in specific heat of the furnace gases. Since heat flows only from a hotter body to a colder one, it is possible for the boiler to reduce the temperature of the gases down to its own, or to the temperature of the water in the boiler, which is presumably the same as the temperature of the steam at the pressure under which the boiler is working. Therefore, the difference between the furnace and the steam temperature is called the available temperature drop for the furnace gases, and the heat in the furnace gases which is above the temperature of the steam in the boiler is called the heat available for absorption. The ratio of the heat which the boiler actually absorbs to the heat which is available for absorption is called the true boiler efficiency. This ratio is the only true measure of the boiler's ability to absorb heat. The boiler efficiencies ordinarily used do not take into consideration the fact that part of the heat in the furnace gases is below the temperature of the boiler and, therefore, can not be absorbed by the boiler.

It has been stated that the heat absorbed by the boiler is proportional to the temperature drop of the furnace gases as the latter pass through the boiler. Applying the same reasoning, it can be said that the heat available for absorption is proportional to the available temperature drop. Therefore the ratio of the two temperatures is the same as the ratio of the two heats. This being so, it is possible to obtain the true boiler efficiency by calculating the ratio of the actual drop to the available drop in temperature of the furnace gases.

This ratio has been calculated for most of the tests reported in this bulletin and is given, with the method of calculating it, in Table 3.

TABLE 3.—*Data used in calculating that portion of true boiler efficiency which is a consequence of heat absorption by convection only.*

Test No.	Fuel used.	Dry fuel fired per square foot of grate per hour (pounds).	Temperature (° F.).			Column 5 minus—		Column 7 divided by column 8.[c]
			In stack.	In furnace.	Of steam.	Column 4.[a]	Column 6.[b]	
1	2	3	4	5	6	7	8	9
1	Run-of-mine coal....	29.62	739	2,673	380	1,934	2,293	84.7
2	.....do...............	41.20	739	2,615	380	1,876	2,235	84.0
3	.....do...............	19.64	646	2,367	380	1,721	1,987	86.6
4	Large briquets.......	21.12	681	2,460	381	1,779	2,079	85.6
5	.....do...............	28.90	802	....	....	....	....	....
6	.....do...............	45.29	919	2,586	379	1,667	2,207	75.6
7	Run-of-mine coal....	30.10	655	2,273	380	1,618	1,893	85.4
8	.....do...............	20.29	597	2,347	379	1,750	1,968	89.0
9	.....do...............	45.41	728	2,624	380	1,896	2,244	84.6
10	Small briquets........	31.68	696	2,662	379	1,966	2,283	86.1
11	.....do...............	45.26	797	2,921	379	2,124	2,542	83.6
12	.....do...............	20.41	583	2,633	380	2,050	2,253	90.9
13	.....do...............	64.83	807	3,097	379	2,290	2,718	84.3
14	Run-of-mine coal.....	21.14	583	2,502	380	1,919	2,122	90.5
15	.....do...............	29.98	668	2,881	383	2,213	2,498	88.5
16	.....do...............	52.12	716	....	....	....	....	....
17	Small briquets........	23.95	637	2,442	383	1,805	2,060	87.6
18	.....do...............	37.28	709	2,765	384	2,056	2,381	86.3
19	.....do...............	51.76	752	2,950	382	2,198	2,568	85.5
20	.....do...............	71.48	817	3,070	380	2,253	2,690	83.8
21	Run-of-mine coal.....	29.07	601	2,498	383	1,897	2,115	89.6

[a] Column 5 — column 4 = approximately the actual temperature reduction effected by the boiler.
[b] Column 5 — column 6 = maximum theoretical reduction of temperature by a perfect boiler.
[c] Column 7 ÷ column 8 = the true boiler efficiency so far only as heat absorption by convection is concerned.

ON TRUE BOILER EFFICIENCY.

The results shown in the last column of Table 3 are platted at the bottom of figure 8 as true boiler efficiency. These points and the curve passed through them show the relation between the true boiler efficiency and the rate of combustion. Thus as the rate of combustion increases from 20 to 71 the true boiler efficiency drops only 4 per cent. The indication is that as the rate of combustion increases the true boiler efficiency remains nearly constant. This is the relation of the temperature of the furnace to that of the flue gas already discussed; that is, the temperature difference between the gas in the furnace and in the flue bears a constant ratio to the temperature elevation of the furnace gases above the temperature of the steam in the boiler, or, in other words, the flue-gas and furnace temperatures rise and fall together, no matter what the rate of combustion may be. It should be borne in mind, however, that in these statements the phrase "heat absorbed by the boiler" refers only to the heat which the boiler absorbs from the furnace gases as the latter pass through the boiler, or the heat which the boiler receives by convection. The boiler receives heat also by radiation from the fuel bed and from the incan-

descent gases while the latter flow through the furnace. The furnace temperature recorded on these tests is the temperature of the gases about as they enter the nests of tubes.

This agrees very well with laboratory experiments made by the United States Geological Survey on small multitubular boilers fed with air heated in an electric furnace. The results of these experiments are to be given in a bulletin of the United States Geological Survey now in preparation.

One point in figure 8, representing a test on large briquets, shows low efficiency because of the unduly high temperature of the flue gases. By referring to figure 5 it is seen that the same test shows unusual flaming in the stack. The explanation is that the flue gas contained a large percentage of combustible gases which burned in the stack and caused the flaming and also produced a much higher flue-gas temperature. This high flue-gas temperature is not chargeable against the boiler for the reason that the heat was generated in the stack after the gases had passed the heating surface of the boiler. Such heat could not be available for absorption.

The true boiler efficiency has been also platted in figure 7 on the same scale as the commonly used boiler efficiency (item 72*) for the purpose of comparing the two. It is quite apparent that the "boiler efficiency" drops much faster than the true boiler efficiency with the increasing rate of combustion. In previous discussion of the middle curve of figure 7 it has been said that the boiler efficiency drops at the high rates of combustion because the furnace fails to develop all the heat in the fuel and not because the boiler does not absorb heat fast enough. This statement is confirmed by the true boiler-efficiency curve; the latter drops only about 4 per cent while the boiler efficiency, or rather the efficiency of the whole steam-generating apparatus which it really is, drops 14 per cent. At least 10 per cent of this total drop of 14 per cent is very likely due to the drop of furnace efficiency.

ON PRESSURE DROP.

The points grouped at the top of figure 9 show the relation between the pressure drop through the fuel bed and the rate of combustion. The pressure drop through the fuel bed was obtained by subtracting the absolute pressure over the fuel bed from the absolute pressure in the ash pit. Although the points do not fall along a single curve, the indication is that the pressure drop through the fuel bed increases with the rate of combustion. With any fuel of uniform size this relation is a necessity; to burn more fuel more air must be passed through the fuel bed, and to pass more air through the fuel bed there must be a higher pressure drop. Different sizes of fuel offer different resistances to the passage of air through them

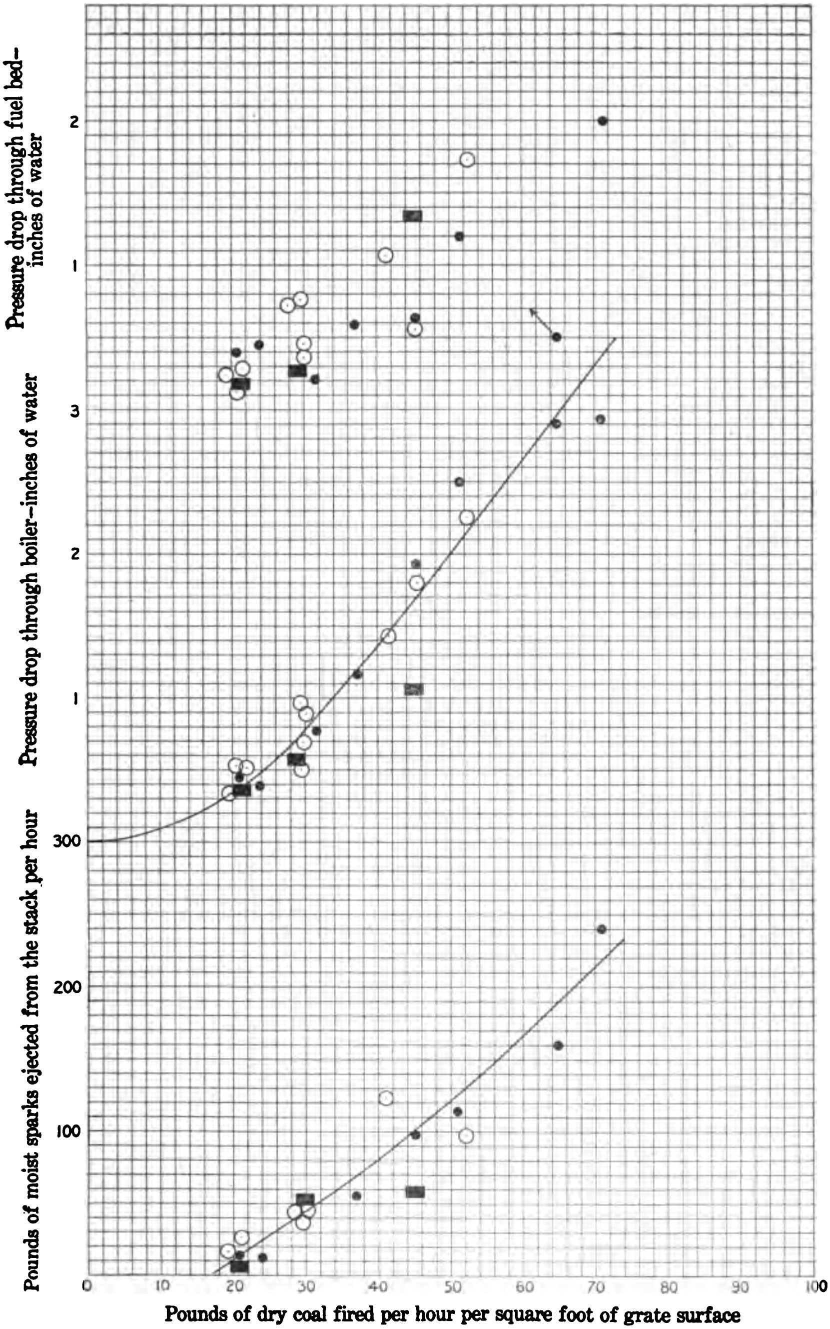


FIGURE 9.—Relation of increasing rate of combustion to (1) pressure drop ("draft") through fuel bed in inches of water; (2) pressure drop through boiler in inches of water; and (3) pounds of moist sparks ejected from the stack per hour.

and therefore different pressure drops must be used with different fuels to obtain the same rate of combustion. As three different kinds of fuels are represented on the figure, the points are somewhat scattered. The run-of-mine coal was a mixture of various sizes and therefore offered higher resistance to the passage of air, and a higher pressure drop than with the briquets had to be maintained to obtain the same rate of combustion.

In the same figure the points of the middle group show the relation between the pressure drop through boiler and the rate of combustion. The pressure drop through the boiler was obtained by subtracting the absolute pressure at the base of the stack from the absolute pressure in the furnace. Since the pressure at the base of the stack was recorded in inches of water below atmospheric pressure and the pressure in the furnace in inches of water above atmospheric pressure, the required difference is obtained by adding the two quantities.

These points fall much better along a single curve than the upper group. This close agreement among the points is due to the fact that the resistance of the gas passage of the boiler remains constant. To put the same volume of gas through the boiler the same pressure drop is needed, no matter what the fuel burned may be, so long as the temperature remains about the same. The curve shows that the pressure drop through the boiler increases a little faster than the rate of combustion. The shape of the curve suggests the law which is commonly used in connection with the flow of gases; that is, the pressure drop through the boiler varies as the square of the rate of combustion.

ON SPARKS.

The points of the lowest group of figure 9 show that the weight of sparks ejected from the stack rises rapidly as the rate of combustion increases. This, of course, can be expected, because in order to obtain a higher rate of combustion a higher pressure drop had to be maintained through the fuel bed, and the resulting increased velocity of gases carried more sparks away. There does not seem to be much difference in the weight of sparks when using the three kinds of fuel; briquets are nearly as bad as run-of-mine coal, at least within the range of the rates of combustion investigated.

ON WEIGHT OF AIR.

The upper curve of figure 10 shows the relation between the weight of air supplied to the furnace and the rate of combustion. The weight of air for platting these points was obtained by multiplying the total weight of "combustible" burned per hour by the weight of air used per pound of "combustible," as figured from the analysis of the flue gases. The curve shows that the total weight of air supplied to the

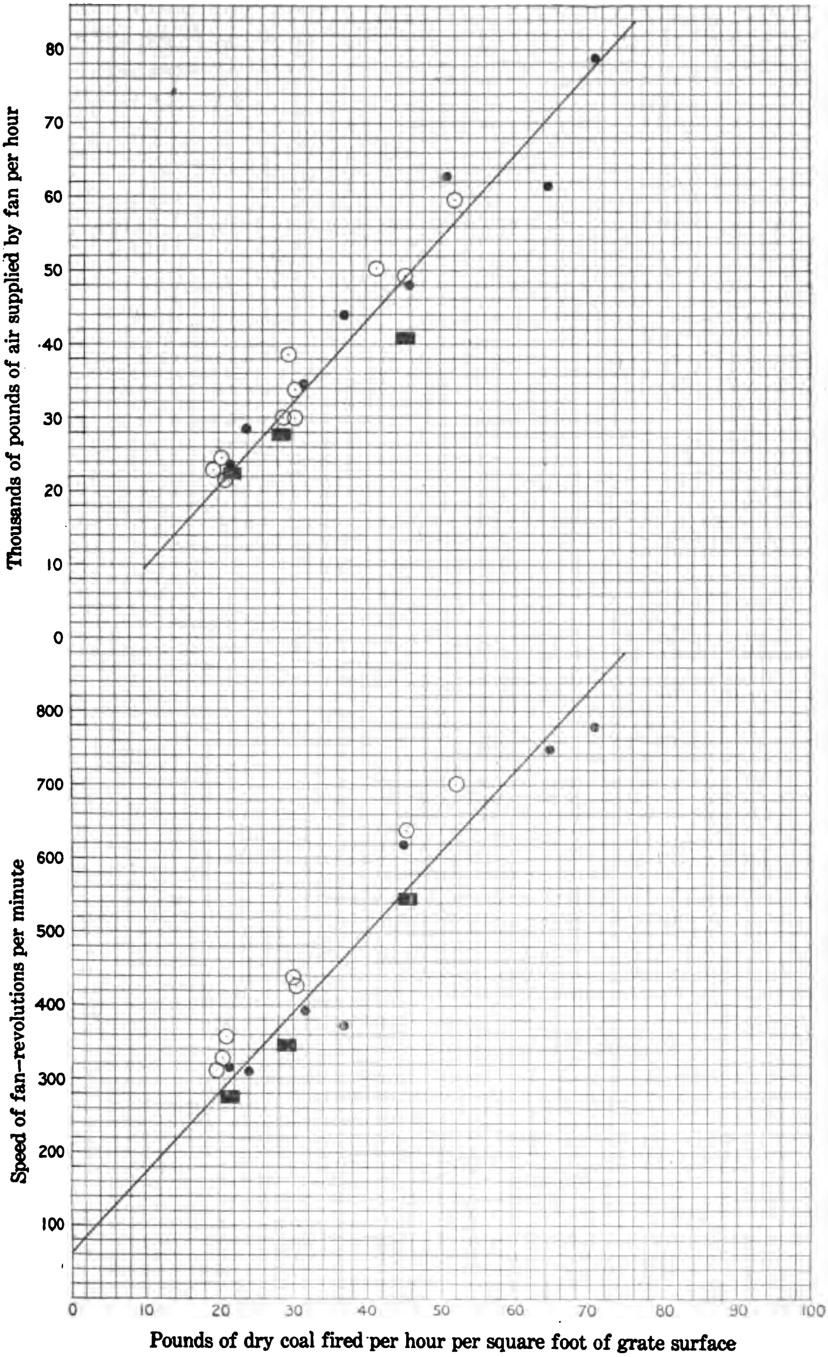


FIGURE 10.—Relation between rate of combustion and thousands of pounds of air supplied by the fan per hour (above), and speed of fan in revolutions per minute (below.)

furnace increases directly with the rate of combustion. In other words, to double the rate of combustion twice as much air must be supplied; to triple the rate three times as much air must be supplied, and so on. This relation is quite natural and could be expected. The kind of fuel seems to make no difference.

ON SPEED OF FAN.

The lower curve of figure 10 shows the relation of the rate of combustion to the speed of the fan, which was obtained by direct measurement with a speed indicator. The curve indicates that the speed of the fan varies directly with the rate of combustion; this means that to obtain twice the rate of combustion the speed of the fan must be doubled, approximately, and to triple the rate the speed of the fan must be tripled, approximately, and so on. It must not, however, be assumed that since the air supplied to the furnace and the speed of the fan vary directly with the rate of combustion the work required from the fan varies in the same way. This is far from being the case. It has been shown in figure 9 that both the pressure drops, through the fuel bed and through the boiler, increase faster than the rate of combustion. This means that when the rate of combustion is to be increased the fan has to supply not only proportionately more air, but that it has to force it against much higher pressure. As the work of the fan is equal to the product of the volume of air which the fan displaces multiplied by the pressure against which this volume of air is forced, it is quite apparent that the work required from the fan increases much faster than the rate of combustion. In Bulletin 367[a] it is shown that the work of a fan varies approximately as the cube of the rate of combustion or the capacity of the boiler.

All points representing raw coal are above the curve (lower curve, fig. 10), and nearly all points representing briquets are below the curve. This means that less work was required from the fan to burn briquets than to burn run-of-mine coal. This fact is undoubtedly due to the smaller resistance of the fuel bed to the passage of air when burning briquets. The run-of-mine coal contained a high percentage of slack, which stopped the air passages in the fuel bed. Then, to obtain the same rate of combustion with coal as with the briquets, greater pressure drop through a fuel bed is required and more work must be done by the fan.

DEDUCTIONS.

ECONOMY.

It was found on many locomotive tests and on some tests made under stationary boilers that briquets gave better economy than run-of-mine coal. The question may be asked why similar results were

[a] Ray, W. T., and Kreisinger, Henry, The significance of drafts in steam-boiler practice: Bull. U. S. Geol. Survey No. 367, 1909, p. 55.

not obtained on the fuel tests made under a torpedo-boat boiler. At present no definite answer can be given.

It may be that the combustion space of the furnace, which is less than one-half of the combustion space in an ordinary locomotive, is far too small to show any of the advantages due to the better burning qualities of the briquets. It may also be that what little betterment is gained by the size and uniformity of the briquetted fuel is more than offset by the increase in percentage of volatile combustible due to the addition of pitch as a binder. Table 4 gives for comparison the proximate analyses of the run-of-mine coal and briquets used in these tests, moisture-free basis. The large briquets, which have shown the lowest efficiency, indicate the largest increase in percentage of volatile matter. The same percentage of pitch was used in making both sizes of briquets. However, as the small briquets exposed to the atmosphere a larger surface than the large ones, compared with their volume, and also as they were exposed longer to the atmosphere before testing, it is possible that more of the pitch was evaporated from the small briquets.

TABLE 4.—*Comparison of proximate analyses of coal and briquets.*

Test No.	Designation of coal.	Form of use.	Proximate analysis of dry fuel.		
			Volatile matter.	Fixed carbon.	Ash.
1	Jamestown 6	Run of mine	18.92	75.53	5.55
2			18.71	74.69	6.60
3			19.91	75.81	4.28
		Average	19.18	75.34	5.48
4		Large briquets	23.07	72.01	4.92
5			23.46	71.60	4.94
6			21.31	73.65	5.04
		Average	22.61	72.42	4.97
7	Jamestown 11	Run of mine	15.10	79.06	5.84
8			16.91	76.93	6.16
9			16.86	76.23	6.91
		Average	16.29	77.41	6.30
10		Small briquets	17.43	76.68	5.89
11			18.29	75.63	6.08
12			17.71	76.31	5.98
13			18.21	75.83	5.96
		Average	17.91	76.11	5.98
14	Jamestown 9	Run of mine	23.10	69.22	7.68
15			22.53	70.59	6.88
16			24.06	71.24	4.70
		Average	23.23	70.35	6.42
17		Small briquets	24.04	70.73	5.23
18			24.01	70.58	5.41
19			23.63	71.12	5.25
20			23.70	71.03	5.27
		Average	23.84	70.87	5.29

COMBUSTION SPACE.

The size of combustion space of a furnace and its relation to the grate area and the rate of combustion is very important with volatile fuels such as soft coal, because a considerable percentage of the combustible has to be burned as gas and tar vapors. In a furnace which affords insufficient space these forms of combustible remain in the combustion space only a fraction of a second, which is far too short a time for their complete oxidation. Table 5 gives, for three furnaces, the usual relation of combustion space to grate area, the rate of combustion, and the average time each cubic foot of gas is allowed to stay in the furnace.

TABLE 5.—*Usual relation of combustion space to grate area, the rate of combustion, and the average time each cubic foot of gas stays in the furnace.*

Type of furnace.	Grate area (square feet).	Combustion space (cubic feet). Total.	Combustion space (cubic feet). Effective when fuel bed is 12 inches thick.	Ratio of columns— 2 and 3.	Ratio of columns— 2 and 4.	Customary rate of combustion (pounds of fuel per square foot of grate per hour).	Gases generated per second (cubic feet).[a]	Time each cubic foot of gas stays in furnace (seconds).
1	2	3	4	5	6	7	8	9
Torpedo boat Biddle...	58.6	136	78	2.34	1.33	40	1,010	0.077
Modern locomotive.....	30	160	130	5.34	4.33	60	780	.17
Stationary boiler, Heine, 200 horsepower..............	35	250	215	7.14	6.14	25	380	.58

[a] Assuming that 20 pounds of gas and water vapor are formed per pound of coal and that the furnace temperature is 2,500° F.

Columns 5 and 6 show that the ratio of combustion space to grate area in the torpedo-boat furnace decreases much more rapidly with the thickness of fire than it does in either of the other two furnaces. A thick fuel bed reduces not only the supply of air to the furnace, but also the available space for the burning of combustible gases and tars. These facts applied to the fuel tests made under a torpedo-boat boiler help to explain why better results were obtained with comparatively thin fuel beds. Column 9 gives approximately the average length of time each cubic foot of gas is allowed to stay within the combustion space of the furnace. In the case of the torpedo-boat boiler the time usually is very short; in fact, too short for any chemical reaction which is not almost instantaneous. For this reason fuels which burn on the grate and not in the space above would be burned most economically in this particular type of furnace. Such fuels, however, are slow burning, and therefore not quite suitable for a torpedo boat where the rate of making steam is very important. Again, the limitations of a torpedo boat do not permit the combustion space to be enlarged. Therefore, the selection of fuel is usually a compromise between efficiency and rate of making steam.

RELATIVE CAPACITY OF STORAGE SPACE.

To determine the approximate relative storage capacity of coal bunkers when filled with run-of-mine coal, small briquets, and large briquets, a large rectangular wooden box was filled even full with each of the three fuels and the contents were weighed in each case. All three fuels were shoveled into the box in the same way as they would be into the coal bunkers of a boat. The box was 8 by 6 feet inside, and 3 feet deep.

When level full the box held 8,593 pounds of coal, 6,645 pounds of small briquets, and 6,272 pounds of large briquets. Considering the capacity of the coal bunkers when filled with coal as 100 per cent, this space when filled with each of the two kinds of briquets is reduced to $6,645 \div 8,593 = 77.4$ per cent for small briquets and $6,272 \div 8,593 = 73$ per cent for large briquets, showing a considerable loss in the storage capacity of coal bunkers when filled with briquets. This is a serious obstacle to the use of briquets for naval purposes.

TRANSFERRING FUEL FROM BUNKERS TO FIREROOM.

The coal bunkers on a torpedo boat are long, narrow spaces, the floors of which are elevated only about 2 feet above the floor of the fireroom. On account of their shape and location a large part of the contents of the coal bunkers must be shoveled out when wanted in the fireroom. The spaces are so narrow that a man can not turn around inside of them with a shovelful. The openings into the bunkers are near their ends, and fuel at the far ends has first to be shoveled to the opening and then out upon the floor of the fireroom. In doing this work the coal shoveler has to dig with his shovel into the coal pile from the top as he recedes toward the farther end of the coal bunker, always facing the end where the opening is. It is comparatively easy to force the shovel into run-of-mine coal, but almost impossible to force it into a pile of briquets. Starting at the opening and forcing the shovel under the briquets on the floor would be a slow process, because as the coal shoveler got farther away from the opening he would have to walk backward to the opening with every shovelful. Besides, the numerous ribs of the boat would be frequently in the way of his shovel. During the test the quickest way of getting the briquets out of the farther portions of the bunker was by throwing them by hand toward the opening and then shoveling them into the fireroom.

CONCLUSIONS.

The following conclusions apply only to the tests of New River run-of-mine coals when burned under a boiler of the Normand type and on vessels of the torpedo-boat class.

There is little or no gain in efficiency in burning briquets of either size.

Both large and small briquets make as much (or more) smoke as run-of-mine coal.

There seems to be more flaming in stack with briquets than with run-of-mine coal.

About the same amount of sparks are emitted from the stack whether briquetted or run-of-mine coal is burned.

When burning briquets the fire does not need to be disturbed; with coal the fuel bed has to be broken up, generally after each firing.

A somewhat higher boiler capacity can be obtained with briquets than with run-of-mine coal.

Steam can be raised more quickly with briquets than with run-of-mine coal.

Run-of-mine coal is transferred much more readily than briquets from the coal bunker to the fireroom.

With briquets the capacity of a coal bunker is reduced by 23 to 27 per cent.

A FUNDAMENTAL PRINCIPLE IN THE COMBUSTION OF SMOKY FUELS.

On page 26 of this bulletin it was reasoned that in the torpedo-boat furnace the combustion of fuels was imperfect because the combustion space was too small and that the combustible gases and tar vapors [a] did not stay within the furnace a sufficient length of time to become completely oxidized. This means that time is an important element in the combustion of fuels.

The combustion of coal in a boiler furnace is a chemical process in which the oxygen reacts with the carbon and the latter's various combinations with hydrogen. This reaction, being between the gaseous oxygen on one side and gaseous, "liquid," and solid combustibles on the other, is very complicated.

The word "liquid" as used in this discussion denotes all the forms of combustible between gaseous and solid; that is, such substances as in a strict physical sense are not gases or solids. For example, if we pour some coal tar in its viscous semiliquid form into a hot coal fire, a very dense brown "smoke" will issue from it. We know that this smoke is not gas; it is also hard for us to believe that all this smoke would consist of tiny, angular pieces of solid carbon. It is perhaps easier to think that at least a part of the smoke is composed of minute globules of the tar which have been boiled off, somewhat like the visible "steam" coming out of boiling water. For lack of better expression, we say that the combustible in the globules is in "liquid" form.

[a] In a strict physical sense these tars are not in the form of vapor at all, but rather in the form of visible mist consisting of minute globules of liquid, or a pasty softening solid. Preston, in his "Theory of heat," defines vapor as transparent gas which is below its critical temperature.

When in the use of a hand-fired furnace a fresh charge of soft coal is spread over the hot fuel bed, the coal is heated up very rapidly and part of the combustible matter is boiled or distilled off immediately after the coal reaches the fuel bed. This combustible which is distilled off is perhaps mostly in the form of gases and such forms as are here called "liquids." There are also numerous tiny pieces of solid fuel in the form of lampblack and even pieces of coal carried along with the gases. The combustible left on the grate is the "fixed carbon" in solid form, which burns there. The gaseous combustible which has been distilled off is free hydrogen, carbon monoxide, and some of the lighter hydrocarbons. The "liquids" are heavy hydrocarbons and carbon-hydrogen compounds of the benzine series, which, although surrounded by gases at a high furnace temperature, may exist as minute tar globules. It is these globules of tars which greatly add to the apparent brown smoky color of the gases. All of these forms of combustible driven off from the fuel bed are in more or less perfect mechanical mixture with the air, with the already-formed carbon dioxide, and with the water vapor resulting from evaporating the moisture in the coal, and from the combustion of part of the free hydrogen. The velocity of chemical reaction (combination) between the combustible gas and the free oxygen (or the rapidity with which the combustible gas burns) depends upon the concentration of the two gases; that is, the rapidity of combustion will be the product of the amount of free oxygen times some power of the amount of combustible gas present in a unit of volume. The combination of simple gases, such as hydrogen and carbon monoxide, perhaps consist of a single reaction, while the combustion of the unsaturated hydrocarbons, as ethylene, and acetylene may be series of two or three, or even more, reactions, the first reactions of each series partly burning the gases and partly reducing them to simple combustibles, either gaseous or solid. Ordinarily, the velocity of these reactions or the rapidity of burning gaseous combustible is high, so that with any reasonable amount of oxygen this combustion is nearly complete in a fraction of a second. The tar vapors, however, being partly in "liquid" form, require, even in the case of a uniform mixture with oxygen, a much longer time for their complete combustion, because oxygen can act only on the surface of each minute globule. As each globule burns, an insulating film of the products of combustion is formed around it, preventing contact with more oxygen. The globules are carried in the current of gas, and since they have very nearly the same velocity, there is little or no friction between the gas stream and the globules. The chief way in which the insulating film around each globule can be dispersed and more oxygen brought into contact with the surface of the globule is by natural diffusion between the gas comprising the film and the free oxygen outside the

film. This process of natural diffusion is rather slow, and as each globule contains many times more combustible matter than a like volume of gas, the process of oxidation of the globules of tar may extend over a considerable length of time, during which they may be carried out of the furnace and cooled below their ignition point. Such unoxidized tar globules appear at the top of the stack as dark smoke, and probably form the greater part of the loss in incomplete combustion.

These tar globules are similar in character to tobacco smoke, which is not a product of combustion, but a product of decomposition; it is not a slightly colored gas, but a large number of tobacco-oil globules held in suspension by the current of gas. Every smoker knows that if he pass the smoke from his cigar through a clean, white linen cloth, the visible smoke which consists of the tobacco-oil globules will condense and leave a light-brown oil spot on the linen, having a very strong, characteristic smell. The tarry globules escaping from a coal fire, if collected and condensed in some such way, generally appear as a thick, black, pasty liquid, having the strong coal-tar odor, which we are accustomed to smell around a certain class of gas producers or around gas works. Tar vapors from a wood fire have a different odor than those coming from a coal fire. In fact, every fuel gives off tar vapors with odors peculiar to that fuel and somewhat different from those of any other.

In the case of a boiler furnace, any attempt to determine the tar loss by volumetric chemical analysis of the flue gases must necessarily fail, because these tars have comparatively little volume; furthermore, they generally condense in the gas-sampling apparatus.

The slow combustion of the tar globules can be made faster by increasing the rate of diffusion of the film of products of combustion enveloping the globule. This can be done by creating a relative velocity between the gas stream and the globules; that is, by making one move faster than the other or by changing slightly the direction of the main stream of gas. The resulting friction facilitates diffusion by a process of scrubbing, which removes from the globules the insulating film of products of combustion. Insertion of brick piers in the path of the gases or changing the cross section of the gas passages so that the gases have to contract and expand perhaps induces such relative difference of velocities.

That some such film as is herein described does prevent the free oxygen from coming into contact with the surface of the globules seems to be certain from the fact that gas samples taken by water-jacketed samplers from a stream of gas apparently rich in the tar vapors show usually several per cent of free oxygen.

As the tar vapors are perhaps a whole series of very complex hydrocarbons, their complete oxidation undoubtedly consists of several

simultaneous or consecutive reactions more or less dependent on each other. This is probably another cause of their slow combustion.

What has been said about the slow combustion of the tars is perhaps in an intensified degree true of the small particles of solid combustible held in suspension by the gases.

By far the larger part of the coal burns on the grate, where the combustion is mostly a reaction between the solid carbon and gaseous oxygen. The rate of formation of CO_2 seems to vary directly with the velocity of the free oxygen passing over the surfaces of the pieces of solid carbon. The higher the blast of air passing through the fuel bed of burning carbon the faster the latter burns, the chemical composition of the products of combustion remaining about the same. Undoubtedly the scrubbing action of the blast of air removes from the surfaces of the solid carbon the film of the products of combustion and facilitates the access of free oxygen. If the fuel bed is not carried too thick, very good combustion of the fixed carbon is obtained without any difficulty.

In the preceding discussion of the combustion of the various forms of combustibles in a boiler furnace it has been shown that the gaseous combustible is easy to burn because it burns quickly, and that the fixed carbon is easy to burn because it stays on the grate until completely burned; also, that the tar vapors, the lampblack, and the tiny pieces of coal held in suspension by the gases are difficult to burn because they burn slowly, and usually can not be kept long enough within the furnace to be completely burned. The proper way to burn coal would be to treat it in such a way as to distill as volatile matter only light, easily burning gases, and leave all the rest of the combustible on the grate and burn it as a fixed solid. Laboratory experiments[a] show that the amount and quality of the combustible driven off the coal by heating depends largely on the rate of heating; that is, when the rate of heating is slow, the total combustible matter driven off as volatile is small in quantity and gaseous in composition, while if the rate of heating the coal is very rapid the total volatile matter driven off is not only high in quantity but contains much tar vapor. It seems as though the hydrogen of the coal must be distilled off before burning and that when the coal is heated slowly the hydrogen on distillation takes only a small amount of carbon with it, leaving most of the latter on the grate as "fixed carbon;" if, however, the coal is heated very rapidly, the hydrogen comes off with a large amount of carbon and escapes as volatile matter, leaving a smaller quantity of the carbon on the grate in a fixed form. These facts bring us to the realization that there is no definite line between "fixed carbon" and "volatile matter." We know, for

[a] See Porter, H. C., and Ovitz, F. K., The nature of the volatile matter of coal as evolved under different conditions: Jour. Am. Chem. Soc. vol. 30 (Sept.), 1908, p. 1486.

instance, that coal tars which escape from a gas producer entirely as volatile matter show from 40 to 50 per cent of "fixed carbon" when subjected to proximate analysis. Similarly, if the tars from a boiler furnace, particularly from a hand-fired one, were caught and analyzed by the proximate method, they would likely show a considerable percentage of "fixed" carbon. This "fixed carbon" of the tar should have been left on the grate and not carried away by the process of distillation.

According to the above, firing coal by hand is not the right way to burn it, because the pieces of coal fall on a very hot fuel bed and are heated in two or three minutes through a range of temperature of about 2,400° F. This is a very high rate of heating and much of the carbon which, with a slow rate of heating would be left on the grate as "fixed," is driven away in combination with hydrogen in the form of heavy tar vapors. These tar vapors generally do not stay long enough in the furnace to burn, and hence leave the stack as smoke.[a]

Most mechanical stokers are designed so that the coal is fed into the furnace gradually, and therefore the rate of heating is slow. The result is that a comparatively small amount of combustible is driven off as volatile matter, and it consists chiefly of easily burning gases, most of the carbon being left and burnt on the grate as fixed carbon; very small amounts of tarry vapors are distilled, whence the success of most mechanical stockers in burning smoky fuel. As an example, on a well-operated chain-grate stoker, it takes perhaps fifteen to twenty minutes to heat the coal through the same temperature range of 2,400° F., which takes only two or three minutes in the hand-fired furnace. In general, the success of these mechanical stokers lies not in the fact that they consume smoke but that they burn the coal without producing much smoke at all.

Tar vapors and other heavy carbon-hydrogen compounds which are the product of distillation of coal under certain treatment burn slowly, and in order to burn them nearly completely they must be kept a comparatively long time within the furnace. To fulfill this condition the furnace must be provided with a large combustion space. Such furnaces, however, are objectionable for obvious reasons. The best remedy probably is to avoid the formation of all these slow-burning volatile compounds by using the principle of the low rate of heating of fresh fuel.

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[a] It must not be understood that these tar vapors are the only constituents of visible smoke. Small particles of carbon or soot, resulting from the decomposition of illuminant gases such as C_2H_4 and C_2H_2 add to the darkness of the smoke; however, the tar vapors probably represent the greatest loss of heat.

SURVEY PUBLICATIONS ON FUEL TESTING AND BRIQUETTING.

The following publications, except those to which a price is affixed, can be obtained free by applying to the Director, Geological Survey, Washington, D. C. The priced publications can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

BULLETIN 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

PROFESSIONAL PAPER 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp., 13 pls. $1.50.

BULLETIN 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

BULLETIN 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp. 10 cents.

BULLETIN 325. A study of four hundred steaming tests, made at the fuel-testing plant, St. Louis, Mo., 1904–1906, by L. P. Breckenridge. 1907. 196 pp. 10 cents.

BULLETIN 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes, in charge. 1908. 299 pp.

BULLETIN 334. The burning of coal without smoke in boiler plants; a preliminary report, by D. T. Randall. 1908. 26 pp. 5 cents.

BULLETIN 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. 76 pp. 10 cents.

BULLETIN 339. The purchase of coal under government and commercial specifications on the basis of its heating value, with analyses of coal delivered under government contracts, by D. T. Randall. 1908. 27 pp. 5 cents.

BULLETIN 343. Binders for coal briquets, by J. E. Mills. 1908. 56 pp.

BULLETIN 362. Mine sampling and chemical analyses of coals tested at the United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp. 5 cents.

BULLETIN 363. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1908. 57 pp., 4 pls.

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MINERAL RESOURCES, 1907. Coal briquetting in 1907, by E. W. Parker. pp. 223–228.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 404

THE GRANITES OF VERMONT

BY

T. NELSON DALE

WASHINGTON
GOVERNMENT PRINTING OFFICE
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CONTENTS.

ILLUSTRATIONS.

THE GRANITES OF VERMONT.

By T. Nelson Dale.

INTRODUCTION.

It is not proposed to present in this bulletin an exhaustive geologic and petrographic account of Vermont granites. For such a work years of geologic exploration and much petrographic skill and study would be required; but it is proposed for immediate economic purposes to locate definitely, describe briefly, and classify all known granites of present or prospective economic value within the State. The method of treating the subject will, like that adopted in the bulletins on the granites of Maine[a] and on those of Massachusetts, New Hampshire, and Rhode Island,[b] be both scientific and economic. Features of general geologic interest presented by the stone and the quarries or their immediate vicinity, as cursorily examined, and features of economic interest, particularly those resulting from the location, character, or structure of the stone, will both receive due attention.

The elementary facts as to the origin, composition, physical properties, texture, structure, variations, discoloration, and decomposition of granite, together with a summary of the methods of classifying, testing, and quarrying it, will be found, in a form intended for general readers, in Bulletin No. 354,[b] pages 9 to 72.

The field work upon which this report is based was done in 1907, when 79 quarries and prospects were visited. One small quarry was visited in 1909. Prof. G. H. Perkins, state geologist, collected data from two prospects. Dr. Albert Johannsen, of the United States Geological Survey, critically revised the writer's petrographic determinations. Mr. W. T. Schaller, chemist, of the Survey, determined the percentages of lime soluble in acetic acid in 10 specimens of granite. Miss Altha T. Coons, of the Survey, has contributed some statistics of Vermont granite production. Dr. G. P. Merrill, of the United States National Museum, has rendered some bibliographic

[a] Dale, T. N., The granites of Maine; with an introduction by George Otis Smith: Bull. U. S. Geol. Survey No. 313, 1907.

[b] Dale, T. N., The chief commercial granites of Massachusetts, New Hampshire, and Rhode Island: Bull. U. S. Geol. Survey No. 354, 1908.

aid. The results obtained by Finlay and Daly from their special studies of certain Vermont granites have been utilized and will be referred to in their place.

As in Bulletins 313 and 354, the number of each specimen described, to which that of one or more thin sections corresponds, is given, so that the description can be verified by consulting the collections at the National Museum. These specimens, except those from idle quarries, have been prepared from blocks selected by the foreman or superintendent. The words "coarse," "medium," and "fine," as applied to granite, are to be understood as in the two previous granite bulletins: *Coarse*, with feldspars over 0.4 inch; *medium*, with those under 0.4 and over 0.2 inch; *fine*, with those under 0.2 inch. The Rosiwal method of estimating mineral percentages has been applied as far as practicable to the principal types of granite described. These types are defined and classified for economic purposes in the table on page 120, a bibliography of the economic geology of granite is given on page 127, and a glossary of scientific and quarry terms will be found on page 130.

The names applied to the various granites in this report are, with a few exceptions, merely local or trade designations. Their employment in this economic bulletin does not affect the standing of any particular name as a geologic formation name.

PART I.—SCIENTIFIC DISCUSSION.

GEOGRAPHIC DISTRIBUTION OF VERMONT GRANITES.

Not until a contour map of the mountainous portions and of the eastern half of the State is completed and a careful geologic survey based upon such a map is made will the geographic distribution and extent of the granite areas of Vermont be accurately known. According to the geologic map of the State traced and compiled by the authors of the state report of 1861 [a] and also according to the geologic map of Orange and parts of Washington and Windsor counties by C. H. Richardson,[b] a series of granite areas, varying greatly in size but mostly small, extend in a north-northeasterly direction between the central Green Mountain axis on the west and Connecticut River on the east for almost the entire length of the State.

The distribution by counties of all the granite quarrying centers and of the prospects included in this bulletin is shown in figure 1. At the extreme north end of the State, in Orleans County, granite is quarried in Derby, east of Lake Memphremagog. Near the northeast corner of Caledonia County, the next county south, there is a granite prospect in Newark; and there are several quarries in Kirby about 14 miles south of Newark. There are also several quarries near the western corner of this county, 20 to 23 miles west of Kirby, in Hardwick; and the quarries of Ryegate and Groton lie near its southern edge. In Washington County, the southern half of which adjoins Caledonia on the west, there are three groups of quarries: The Woodbury quarries at the north, and east of them a prospect in Cabot; south of Woodbury the quarries in Calais; and 20 miles southwest of Woodbury and 8 miles southeast of Montpelier, the quarries of Barre, which is the chief granite-producing center of the State. A few of the Barre district quarries lie south of the Orange County line. About 20 miles southwest of Barre is the granite prospect of Randolph in Orange County. In the northern part of Windsor

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[a] Hitchcock, C. H. and E., jr., and Hagar, A. D., Report on the geology of Vermont, vol. 2, 1861, Pl. I. This map, valuable as it is, can to-day hardly be regarded as more than a reconnaissance map. Some of its granite areas are wrongly located, and granite has been found where the map does not show any.

[b] Richardson, C. H., The terranes of Orange County, Vt.: Rept. State Geologist of Vermont, 1902, Pls. IX and IX, A.

County is the small but important white granite area of Bethel; 10 miles southwest of it is a quarry in Rochester, and 33 miles south-southeast of Bethel and near the Connecticut is the green syenite of Mount Ascutney in Windsor and West Windsor. Finally, in Wind-

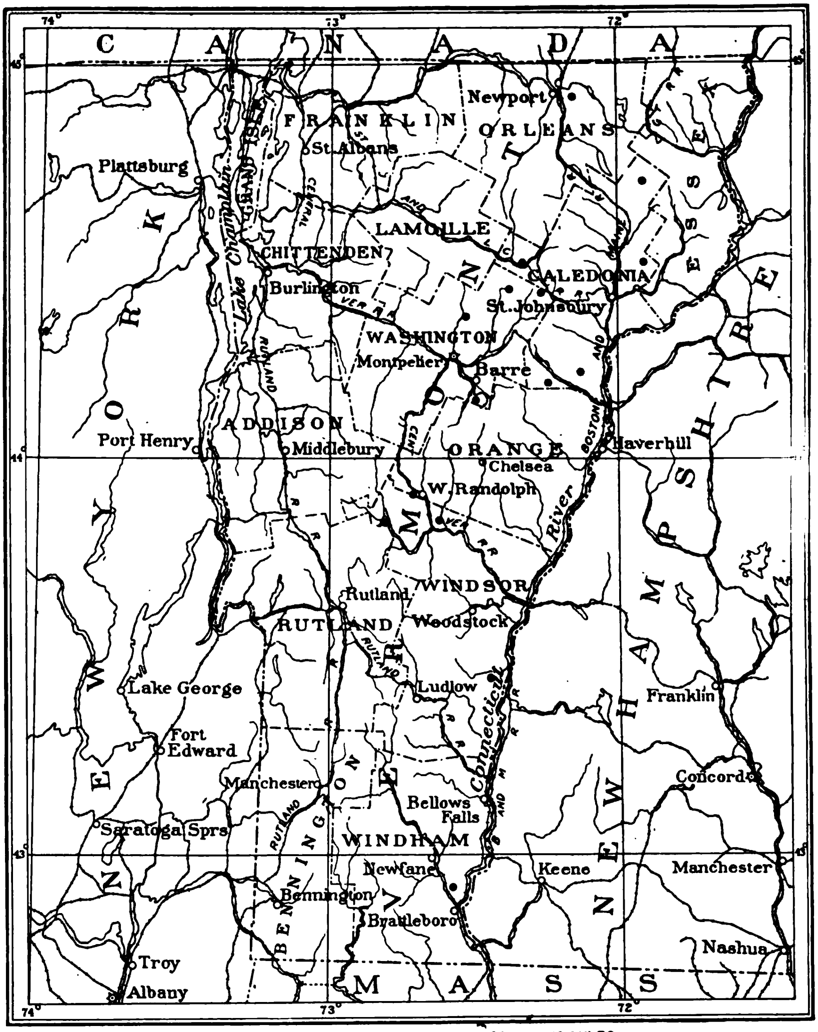

FIGURE 1.—Map of Vermont, showing granite centers and prospects (•).

ham County, toward the southern border of the State, 37 miles south-southwest of Ascutney, near Brattleboro and the Connecticut, are the light-granite quarries of Dummerston.

GENERAL PETROGRAPHY OF VERMONT GRANITES.

The granites of this bulletin fall into three petrographic groups: Biotite granites, quartz monzonites, and hornblende-augite granites. In biotite granites the mica is almost entirely the black magnesia mica known as biotite. In quartz monzonite the soda-lime feldspar occurs in unusual amount, nearly equaling or even exceeding that of the potash feldspars. In hornblende-augite granite the dark silicates, hornblende and augite, take the place of the micas. The gray granites of Barre, Calais, and Woodbury and the pinkish of Newark are biotite granites. This granite also occurs at one of the Ryegate and one of the Kirby openings. The white granites of Bethel, Randolph, Rochester, the very light gray of Dummerston, the gray of Cabot, Derby, Groton, Hardwick (Buffalo Hill), Kirby, South Ryegate, and Topsham are quartz monzonites. The green syenite of Mount Ascutney is a hornblende-augite granite.

As a paragraph on the petrographic characteristics of the stone of each of these places precedes its detailed description in connection with that of the quarries it will suffice here to note the peculiarities of some in each group.

Biotite granite.—In "Barre granite" the plagioclase ranges from oligoclase-albite to oligoclase and oligoclase-andesine. The amount of $CaCO_3$ indicated by two acetic acid tests is nearly 1 per cent, and the orthoclase particles show much carbonate. A marked feature of this granite is the freshness of its microcline and the general kaolinization and micacization of its orthoclase. Some particles of orthoclase inclose microcline. In two dark-gray granites of Barre the contrast between the hammered and cut face is as marked as it usually is in diorites and quartz monzonites, indicating the presence of more plagioclase than in ordinary biotite granites, a feature which the microscope corroborates. In the stone of Calais, which resembles that of Barre, the feldspar, second in abundance, is oligoclase-albite. In the "Woodbury granite" it is oligoclase-albite to oligoclase, exceptionally oligoclase to oligoclase-andesine, and the $CaCO_3$ is 0.28 per cent. The biotite-granite of South Ryegate has oligoclase and only 0.05 per cent of $CaCO_3$. The granites of Kirby and Newark have albite to oligoclase-albite and the latter has 0.41 per cent of $CaCO_3$.

Quartz monzonite.—The coarse white granite of Bethel contains oligoclase and its mica is mostly muscovite. None of the sections or polished specimens obtained show magnetite or pyrite. The only available analysis shows only 2.56 per cent of CaO and the $CaCO_3$ indicated by acetic acid test is only 0.12 per cent. The flow structure is marked by courses of discoid nodules of mica described more fully on page 25. In the coarse white granite of Rochester the feldspar is largely albite to oligoclase-albite. Muscovite is in conspicuous

aggregates, roughly parallel, producing a gneissoid structure. It is also in minute scales through the feldspars. The amount of $CaCO_3$ indicated is unusually high, 2.46 per cent. The very fine white granite of Randolph has albite to oligoclase-albite, and the muscovite is in scarcely perceptible scales and in finer microscopic ones in the feldspars. The $CaCO_3$ indicated is 0.66 per cent. The very light-gray medium-grained granite of Dummerston has oligoclase to oligoclase-albite and both micas. These are intergrown and bent or twisted with sericite stringers extending from them into the other particles. Crush borders appear about quartz and feldspar. The $CaCO_3$ indicated is 0.125 per cent. The dark-gray stone of Cabot has oligoclase and the mica is almost entirely biotite. The light-gray granite of Derby has oligoclase and both micas. No pyrite or magnetite was detected. The $CaCO_3$ indicated is only 0.09 per cent. The bluish-gray granite of Groton and Topsham has oligoclase and the mica is nearly all biotite. The very dark-gray granite of Buffalo Hill in Hardwick has oligoclase to oligoclase-andesine. The percentage of quartz is low, 21.75, and that of biotite high, 16.19. The gray granite of South Ryegate has oligoclase and its mica is almost entirely biotite.

It will be observed that the microscopic descriptions of these various granites note the arrangement of the cavities within the quartz particles in intersecting sheets and their relation to the rift and grain cracks.[a]

Hornblende-augite granite.—This is the olive-green syenite, "nordmarkite phase" of Daly, exhaustively described in his monograph on Mount Ascutney.[b] Its feldspar appears to be albite and oligoclase more or less obscurely intergrown with orthoclase and also rarely occurring separately. Biotite is present in places. Daly has shown experimentally that the green color which appears soon after exposure is due to the oxidization of extremely minute blackish granules of ferrous oxide in the feldspars and to the combination of the yellowish-brown color from the limonite thus produced with the bluish-gray of the unaltered feldspar. To judge from what has been found in other green granites and from the presence of allanite in this rock, a part of this limonite stain is probably due to the oxidation of allanite particles.[c] Daly estimates that this granite contains about 6 per cent more soda-lime than potash feldspar. The strong contrast of shade between its cut and polished surface, as shown in Plate V, *B*, also points to a large percentage of soda-lime feldspar.

[a] This subject is discussed and illustrated in Bull. U. S. Geol. Survey No. 354, pp. 42–48 and fig. 1.

[b] Daly, R. A., The geology of Ascutney Mountain, Vermont: Bull. U. S. Geol. Survey No. 209, 1903.

[c] See Bull. U. S. Geol. Survey No. 354, p. 52 and fig. 3.

GEOLOGIC RELATIONS OF VERMONT GRANITES.

These studies have not thrown new light on the problem of the geologic relations and age of the granites, although they have brought out some previously known facts in greater definiteness and detail.

The biotite granite of Barre contains inclusions up to 57 by 10 by 6 feet of quartz-biotite-muscovite schist and quartz-biotite schist interbedded with quartzite, the details of which are described more fully on page 18 and shown in Plate II, *B*. At two or more of the Barre quarries (pp. 21, 23), the granite is in contact with a similar schist, and minute dikes of pegmatite, starting from the granite surface, penetrate the schist, which near the contact is spotted with granitic lenses as described on page 22. The schists and mica slates of Barre are in many places spangled with biotite and ilmenite (?). As they contain beds of quartzose crystalline limestone they are clearly of sedimentary origin. (See p. 49.)

On Robeson Mountain in Woodbury the contact of granite and schist is also observable. (See p. 23.) Minute pegmatite dikes from the granite surface penetrate the schist, and the granite carries inclusions of the schist measuring up to 25 by 10 feet. The schist of the original capping here is a biotite-muscovite-quartz schist containing beds of dark calcareous muscovitic, or in places epidotic, quartzite. At one quarry a small inclusion of fine-grained quartzose marble was found. These beds are also all of sedimentary origin.

The southern face of Blue Mountain in Ryegate consists of schists and very quartzose mica slate; its upper portion is granite, mostly quartz monzonite. This also contains inclusions of schist (quartz-microcline-biotite) as described on page 19 and shown in Plate II, *B*.

The coarse white quartz monzonite of Bethel is bordered by a zone of fine-grained, more biotitic, and thus grayish quartz monzonite produced by more rapid cooling along the contact with a schist mass. The details of these relations are given on page 20. In places the schist is a fine-grained garnetiferous mica slate with small calcareous beds spangled with biotite. The "Bethel granite" contains inclusions up to 21 by 12 by 5 inches, of very fine black biotite-orthoclase-oligoclase schist apparently not related to the schists and slates surrounding the granite area.

At one quarry in Derby the foreman stated that a dark slaty rock occurred in contact with the granite (quartz monzonite with both muscovite and biotite) on the west, the plane of contact being very steep; but this was covered in 1907 by the falling in of drift.

Schist occurs in the village of Adamant in Calais, within a small fraction of a mile of a ridge of biotite granite.

On Buffalo Hill in Hardwick a very biotitic quartz monzonite is in contact with a medium-grained biotite-quartz schist containing zoisite.

The inference from the contacts and inclusions referred to is that the gray biotite granite of Barre, Calais, and Woodbury, the white quartz monzonite of Bethel, and the gray of Ryegate and of Buffalo Hill in Hardwick, and probably that of Derby, were intruded into certain mica schists and mica slates which are metamorphosed clayey and sandy sediments. Whether the intrusion of granites of such diverse characters as those of Barre, Bethel, and Hardwick was simultaneous can not yet be determined.

The green syenite (hornblende-augite granite) of Mount Ascutney in Windsor is in contact with a mass of schist which crops out along the base of the mountain a little below the Norcross quarry and has been carefully traced by Daly on three sides of the syenite mass and mountain.[a] He has also described the changes brought about in the schist by the intrusion of the syenite[b] and shows a biotite granite intrusive in syenite on the eastern flank of the mountain.

In view of the pressure needful for the formation of granite the original thickness of the schist masses into which these various granites were intruded must have been very considerable. The present granite surfaces have only become exposed by the erosion of those schist masses. Views have changed as to the age of these schists. On Hitchcock and Hager's map the granite areas are represented as surrounded by "calciferous mica schist" which was regarded as not later than Devonian.[c] Richardson in his papers and map[d] subdivided the "calciferous mica schist" belt of Hitchcock and Hager into a calcareous formation (in places a marble but containing schist phases) which he finally designated Waits River limestone, and an overlying noncalcareous schist member, the Vershire schist. He associates this latter formation with a certain belt of slate which flanks the central Green Mountain axis on the east and extends from Lake Memphremagog south to Barnard and includes the roofing slate of Northfield and Montpelier. This slate he finally designated the Memphremagog slate. About 3 miles west of the head of Lake Memphremagog, at Willards Mills, Castlebrook, Magog, Province of Quebec, this slate bears abundant graptolites of lower Trenton age, and he also cites finds of crinoid stems and crushed graptolites at several

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[a] Daly, op. cit., map, Pl. VII.

[b] Idem, pp. 33, 34.

[c] Op. cit., vol. 1, p. 470.

[d] Richardson, C. H., The Washington limestone in Vermont: Proc. Am. Assoc. Adv. Sci., Boston meeting, vol. 47, 1898, pp. 295-296; also, The terranes of Orange County, Vt.: Rept. State Geologist of Vermont., n. s. 3, 1902, pp. 84, 97, 98, Pl. IX; and The areal and economic geology of northeastern Vermont: Rept. State Geologist of Vermont, n. s. 5, 1906, pp. 86, 90; also, The geology of Newport, Troy, and Coventry: Rept. State Geologist of Vermont, n. s. 6, 1908, pp. 274-279.

points in the Waits limestone.[a] In his last paper (p. 279) he subdivides the Memphremagog slate at the north into three members, separated by two limestone members, and places them all in the Ordovician.

Daly, basing his opinions on Richardson's results and inferences, regards the schist of Mount Ascutney as of Trenton or pre-Trenton age and the intrusion of the syenite as "of later date than the last great period of rock folding which has affected the Ascutney region," and says that "the balance of probability makes them of post-Carboniferous and pre-Cretaceous age." [b]

Great difficulties have been experienced on the west side of the Green Mountain range in distinguishing slates and schists of Cambrian, Trenton, and upper Silurian age, because of their petrographical identity in places and also because of the unexpected unconformity between the Cambrian and Ordovician, and the frequence of faults, as well as the general obscuration of original structure by cleavage. In view of that it will be well to proceed cautiously in discussing the age of slate and schist belts on the east side of that range. This is the more important because of the uncertainty of the geologic mapping, owing to the want of contour maps. In such a territory paleontologic evidence should be confirmed by carefully established areal and structural relationships in order to obtain final age determinations.

With the understanding that the age determinations obtained thus far are, for the reasons given, somewhat provisional, the schists and slates of central and eastern Vermont into which the various granites were intruded may be regarded as of Ordovician age and the intrusions as having taken place not during the post-Ordovician mountain-making movement, but during that which occurred at the close of Devonian or of Carboniferous time.

Evidences are not wanting in the composition and microscopic structure of the granites and in their larger structures as exposed at the quarries that since their intrusion they have been subjected to one and possibly several crustal movements. (See pp. 17, 56, 57.)

The basic dikes which traverse the granite or their inclosing schists at Barre, Groton, and Mount Ascutney are of later, possibly Triassic date.

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[a] See Richardson, op. cit., Rept. State Geologist of Vermont, 1902, pp. 94–98, and 1906, pp. 112–114; also 1908, pp. 290, 291.

[b] Op. cit., pp. 20, 21.

OUTLINE OF THE EARLIER GEOLOGIC HISTORY OF VERMONT GRANITES.

The general earlier history of the granites and associated rocks of eastern Vermont may be tentatively put in the following simple form:

(1) In Algonkian time a period of sedimentation followed by the intrusion of granitic rocks into the sedimentary beds. These granites are the present gneisses of the Green Mountain range.

(2) At the close of Algonkian time a crustal movement metamorphosing the Algonkian sediments into schists and the granites into gneisses. This movement was accompanied by folding and elevation. The earlier mountain system of the State was thus formed.

(3) In early Paleozoic time the submergence of a large area of Algonkian rocks and the deposition thereon of sediments resulting from the erosion of Algonkian land masses, together with calcareous sediments largely of organic origin.

(4) At the close of Ordovician time a crustal movement took place, metamorphosing the Cambrian and Ordovician sediments into schist, slate, and marble, and powerfully folding and also elevating them. Some of these schists and slates are those which now surround the granite areas in the eastern half of the State.

(5) After a long time interval, probably at the close of Devonian or Carboniferous time, another crustal movement occurred, accompanied by the intrusion of the schist mass by granitic material in a state of fusion with superheated water. The intrusion produced in places further changes in the schist and also injected it with dikes of pegmatite. Fragments of the schist became included in the granite.

(6) Not long after the crystallization of the granite it was traversed by granitic dikes (pegmatite and aplite).

(7) The schist and granite masses were traversed, possibly in Triassic time, by basic dikes (diabase, etc.).

(8) Atmospheric erosion of the Paleozoic schists and slates, begun at the close of Ordovician time, has finally removed those parts of the schist mass which covered the granite domes. This process of erosion has been accelerated by successive uplifts.

IMPORTANT GEOLOGIC FEATURES AT THE QUARRIES.

The following paragraphs are devoted to those geologic features of Vermont granite quarries which are of general interest because of their bearing upon the origin and constitution of granite.

DOUBLE-SHEET STRUCTURE.

Robeson Mountain, in Woodbury, is a narrow granite ridge, attaining an elevation of about 1,100 feet above Hardwick station and some 930 feet above Woodbury (Sabin) pond. It is from 300 to 400 feet above the hollows on either side of it. Its axis trends from N. 80° E. to S. 70° W., describing a slight curve. Near its west-southwest end the Fletcher quarry cuts the ridge from southeast to northwest, and in 1907 had reached a depth of 40 feet. The sheets exposed here are from 1 to 5 feet thick, horizontal at the top of the ridge, but curving over on the southeast with a dip of 15° to 30°, as shown in Plate IV, *B*, and determining the slope of the ridge on that side. These sheets are, however, intersected by another set from 5 to 9 feet thick, dipping 5° to 10° S. 70° W. in the direction of the axis of the ridge. In the Woodbury Granite Company's quarries, roughly about 1,750 feet N. 80° E. of the Fletcher quarry, the sheets at the top of the ridge turn, dipping to the northern horizon. Lower down on the southeast side of the ridge they are from 2 to 18 feet thick and dip 20° SSE., with an intersecting set which is horizontal and evidently corresponds to the second set of the Fletcher quarry.

The only explanation offered for this double-sheet structure is the existence at some time of a secondary compressive strain operating differently from that which produced the primary sheet structure to which the ridge owes its form, and giving rise to a nearly horizontal set of joints or sheet partings. There is now a marked compressive strain in the Fletcher quarry, operating from northeast to southwest, parting the sheets and giving rise even in the upper part of the quarry to horizontal strain fractures. Its existence lends support to such an explanation. In 300 granite quarries visited thus far by the writer this is the first case of double-sheet structure or horizontal jointing observed.

COMPRESSIVE STRAIN.

The existence of compressive strain in the granite quarries of New England has long been known. It has also been observed in other places and is believed to bear on the origin of sheet structure.[a] The effects of this strain have been noted at the following quarries in Vermont: The Woodbury Granite Company's quarry at Bethel, direction of strain, east-west; certain quarries in Barre—Boutwell, strain north-south; Bruce, north-south, strong; Wells-Lamson, north-south; Canton, west-east; in Woodbury, Fletcher quarry (see above), about northeast-southwest; in Groton, Benzie

[a] See Bull. U. S. Geol. Survey No. 313, 1907, pp. 32-37, Pl. VII, *A*; and Bull. No. 354, 1908, pp. 25, 28.

quarry, in all directions; in Ryegate, on Blue Mountain, Tupper quarry, east-west; in Dummerston, Black Mountain, Lyons quarry, N. 10° E. to S. 10° W., marked.[a]

The usual effect of such a strain is the closing of channels or the crushing of cores between drill holes. Figure 2 is reproduced from a sketch. A fracture or fault plane has arisen extending tangentially from the side of one drill hole to that of the next and a slippage of part of the core has occurred along it, giving the drill holes an elliptical outline and bringing them nearer together.

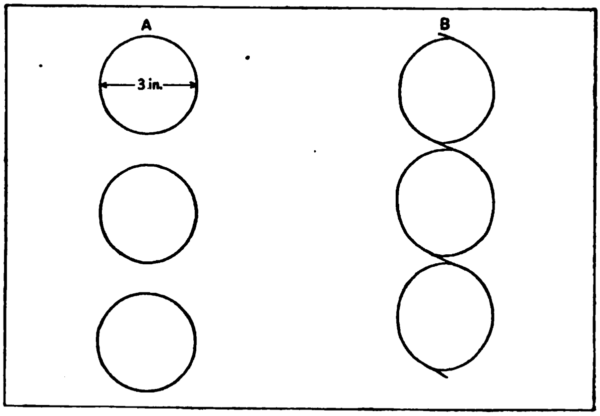

FIGURE 2.—Channel holes at Canton quarry, Barre, showing effect of compressive strain. A, Original drill holes, 3 inches in diameter; B, the same after operation of strain. Displacement along fractures, 1 inch.

SCHIST INCLUSIONS.

Among the notable features of Vermont granite quarries are the schist inclusions. Those at Barre have been briefly referred to by Finlay.[b] Eighteen schist inclusions were noticed by the writer in the Barre quarries: Three at quarry 32 (Pl. I); one of these, 25 by 10 by 10 feet, has a foliation striking N. 30° W. and dipping 60° E.; another is 20 by 8 by 5 feet. The granite is slightly darker for a space of 7 feet from these inclusions. At quarry 25 several measure up to 8 by 2 feet. At quarry 8 two are 10 by 6 by 2 to 3 feet. One at quarry 6 is 20 by 5 feet. One at quarry 10 is 30 by 3 feet, tapering. The largest was at the Boutwell quarry, No. 1, measuring 57 by 10 by over 6 feet, with a foliation striking N. 10° E. and dipping 55° W. Another, 10 by 8 feet, has a foliation striking north and dipping west. Some of these do not seem to have suffered much horizontal displacement, for their foliation nearly agrees with that of the schist capping. In others it differs greatly.

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[a] See Bull. U. S. Geol. Survey No. 354, Pl. VIII, *B*.

[b] Finlay, George I., The granite area of Barre, Vt.: Rept. Vermont State Geologist, No. 3, 1902, p. 51.

The larger Boutwell quarry inclusion was examined in detail. Parts of it are lustrous dark-gray muscovite-biotite-quartz schist spangled with biotite flakes (0.15 inch long) and with garnets (about 0.05 inch). Parts of it consist of small beds of medium greenish gray fine-grained quartzite (grains to 0.2 inch) alternating with dark beds of quartz-biotite schist. The quartzite bands contain plates of green hornblende (to 0.75 by 0.37 millimeter) and larger garnets which inclose the quartz grains of the rock. The schist bands contain similar plates of biotite lying transverse to the bedding and the foliation. Both kinds of bands contain lenses of carbonate (up to 0.37 millimeter) and irregular particles and crystals of zoisite and epidote. As the schists of Barre away from the granite are spangled with various minerals (see p. 49) it is hardly possible to determine which if any of the isolated minerals in this mass was formed at the time of the granitic intrusion. The hornblende and garnet may have been. A few inches of the underside of this inclusion consist of interbanded granite and schist, the schist having evidently at the time of the intrusion been broken into slivers along its schistosity, and the semiliquid granite having been forced in between them. The specimen in Plate II, *B*, at the left, is from this point. It shows two minute dikes of granite (0.5 to 1.2 inches wide) penetrating the schist and ramifying. The main ones follow the foliation but the minor branches form very acute angles with it and taper out. A thin section made across one of these little dikes and the inclosing schist shows the former to be the typical biotite granite of Barre and the latter a quartz-muscovite-biotite schist spangled with biotite plates (to 0.1 inch). The quartz of the granite shows marked strain effects. The demarcation between granite and schist is sharp and no effect of granite upon schist appears.

At the Morrison quarry on Blue Mountain in Ryegate two schist inclusions were noticed measuring 8 by 4 and 3 by 1 foot. The edge of the larger one is injected with granite which fills lenticular spaces, as shown in Plate II, *B*, right. In another specimen the schist has sharp plications, 5 inches high, with lenses of smoky quartz parallel to them, but the nearest edge of the inclusion is nearly a plane surface. A thin section, 1.6 by 0.7 inches, across the edge of this inclusion shows a little granite dike, the quartz monzonite of the quarry, 0.3 to 0.6 inch thick, with schist on both sides. The latter is a quartz-microcline-biotite schist with a little muscovite and rare grains of oligoclase. It has lenses of biotite and muscovite in which large scales of each mica lie at right angles to one another. The sheets of cavities in the quartz of the granite are about parallel to the course of the dikelet and the foliation of the schist. Two other sections of the schist show much apatite in minute crystals and rare particles of allanite. The sheets of cavities in the quartz

particles of the schist are at right angles to its foliation and do not penetrate the quartz of the granite.[a]

The general inference from these observations is that where a rock already schistose becomes included in granite the two may become somewhat minutely interbanded because of the ready fracture along the schist foliation, and that where such interbanding occurs the mineral changes in the schistose rock may be relatively slight.[b]

CONTACT PHENOMENA.

Those places where quarried granite is in contact with schist or slate have already been mentioned. At some of the Bethel, Barre, and Woodbury quarries the contact phenomena are of sufficient general interest to warrant more detailed descripitons.

BETHEL.

As already stated, the white granite at Bethel appears to be encircled by a zone of finer-grained light buff-gray granite, which is about 40 feet thick. Both rocks are quartz monzonites, but the finer contains more biotite scales than the coarser, and they are mostly very minute and evenly distributed. On the west side of the Ellis quarry the plane of contact between the coarse and fine granite strikes N. 15° W. and dips 60° E. The fine-grained granite is in contact on the west with a finely plicated, very fine grained quartz-muscovite-biotite schist, and this granite is finer grained at its contact with the schist than it is 20 feet away. The plane of contact strikes and dips about as that between the two granites, and the plications of the schist run parallel to this plane but are crossed by a slip cleavage striking N. 70° W. and dipping 25° WNW. The relations are shown in figure 3. Figure 4 shows how the granite has been molded by the minute wrinkles in the schist. The schist contains a few small garnets and plates of magnetite. In the glassy zone the particles range from 0.009 to 0.03 millimeter. In the next the porphyritic feldspars measure as high as 0.92 by 0.5 millimeter. There are thus four grades of texture in the granite: The glassy, 1 to

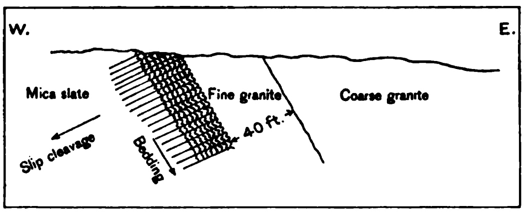


FIGURE 3.—Contact of quartz monzonite on the west side of Ellis quarry, Christian Hill, Bethel, Vt., showing relations of zone of fine granite to coarse granite and to bedding and cleavage of schist.

[a] See Bull. U. S. Geol. Survey No. 354, p. 46.

[b] In connection with this and the next subject the general reader will find some instructive matter in Kemp, J. F., A handbook of rocks for use without the microscope, 4th ed., New York, 1908: Generalities regarding contact metamorphism.

2 millimeters thick; the very fine (porphyritic, at least toward the glassy), about 20 feet wide; the fine with feldspar and mica not over 1 millimeter, about 20 feet wide; and the coarse with feldspars up to 0.4 and 0.5 inch and mica to 0.3 inch, over 200 feet wide.

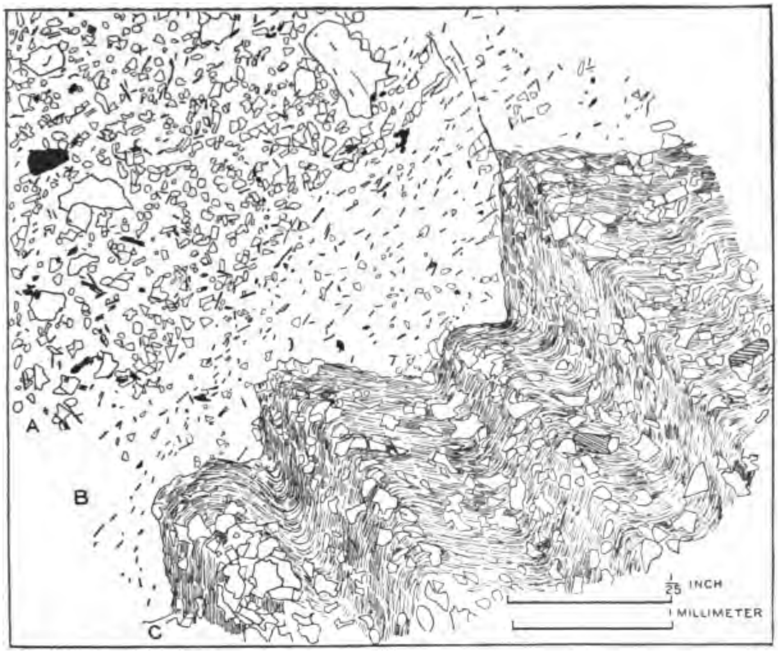


FIGURE 4.—Camera lucida drawing of enlarged thin section across contact of schist and granite at Bethel, Vt., shown in diagram in figure 3. A, Fine granite with some larger porphyritic feldspars and biotite scales. The finer undistinguishable particles of matrix are not shown. B, Zone, 1 to 2 millimeters wide, of glassy material with but few quartz and feldspar particles and biotite scales (in black); most of the latter with their long axis parallel to the general contact surface; a few at right angles to it. A fracture with limonite stain crosses this zone. C, Sharply plicated schist of fibrous muscovite with a little biotite and much quartz (unshaded particles). The two shaded particles are nonmetallic opaque mineral.

BARRE.

The schist which overlies the granite is well exposed at several quarries. Finlay [a] finds a darkened, more biotitic rim about a centimeter wide in the schist along the granite contact. At two quarries contact phenomena were well exposed at the time of the writer's visit. At the Anderson quarry (No. 8, Pl. I) the under surface of the schist is coarsely serrate, forming as it were a series of folds, which, however, are not structural. The granite is darker for a space of 25 feet from the schist, and a foot-thick pegmatite dike borders one of the schist tongues. (See fig. 5.)

[a] Op. cit., p. 51, and Pl. VIII.

In the southern corner of this quarry pieces of the mica slate have scaled off from the mass and been carried a few inches into the granite. (See fig. 6.) At this point the schist is a purplish-gray, very quartzose mica slate of quartz-feldspar-biotite, in places with muscovite also, in others without feldspar. Generally the rock resembles the mica slates used for whetstones. The slate has little dikes of pegmatite which start from the granite surface with a thickness of 0.5 inch and taper out at a distance of 4 feet. The course of these dikes has no reference to the cleavage of the slate and their thickness is apt to be very irregular. The pegmatite consists, in descending order of abundance, of quartz, orthoclase, microcline, oligoclase-albite, and biotite. The quartz has cavities in sheets, some parallel to the dike, others across it. Minute particles of slate are here and there included in the pegmatite. The slate within

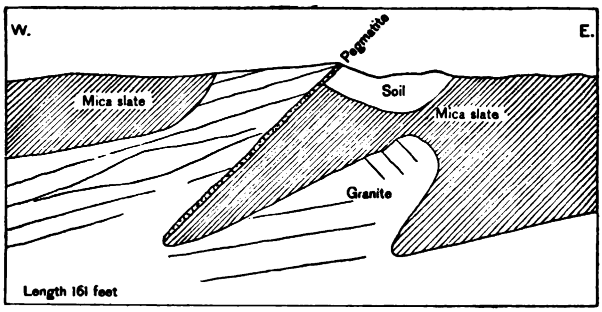


FIGURE 5.—Diagrammatic sketch showing relations of granite and mica schist and slate at Anderson quarry, Barre, Vt. Length, 175 feet.

a few inches of the granite is marked by very fine-grained, oval greenish-white spots, 0.1 to 0.5 inch and rarely 4 by 2 inches. These lenses lie with one of their major axes in the plane of the slaty cleavage. In some the biotite is zonally arranged, or the lens has a flange of biotite extending considerably beyond it and parallel to the slaty cleavage. Small ones (0.15 to 2.2 by 0.1 to 1 millimeter) were found in thin section to consist of granitic quartz with biotite and muscovite scales transverse or diagonal to the longer axis of the lens, and to be surrounded by a zone, 0.11 millimeter wide, of apatite particles. One has a little pyrite; another has apatite disseminated throughout it; another a little carbonate. The schist for a little space about the lens is finer grained than it is farther away. The little dikes do not show apatite except in rare, very minute prisms. Such dikes and lenses are shown in figure 7.

These lenses have usually been regarded as the result of vaporous impregnation from the granite along the cleavage foliation.[a] The slate about the lenses shows dark intersecting streaks which are due to more or less complete fractures lined with chlorite with a wide border of exceedingly minute undeterminable black particles.

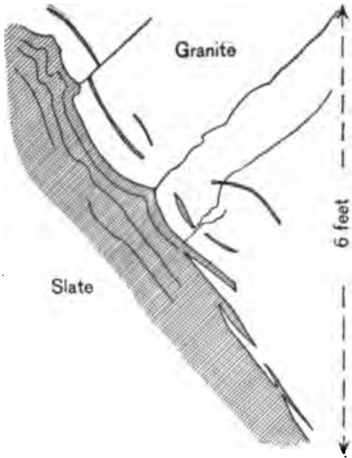


FIGURE 6.—Details at contact of mica slate and granite at south corner of Anderson quarry, Barre, Vt., as viewed along the strike of cleavage. Height, 6 feet.

At the Bailey quarry (No. 6, Pl. I) the contact is somewhat obscured by an inclusion which lies very near the schist capping. As the bedding of the inclusion strikes nearly east and west and that of the capping N. 20° to 60° E., the inclusion has been revolved. Both capping and inclusion have been shattered and injected with aplite and pegmatite. The schist, which is like that of the large inclusion at the Boutwell quarry, described on page 18, consists of little beds of whitish quartzite dotted with greenish hornblende and a few garnets, alternating

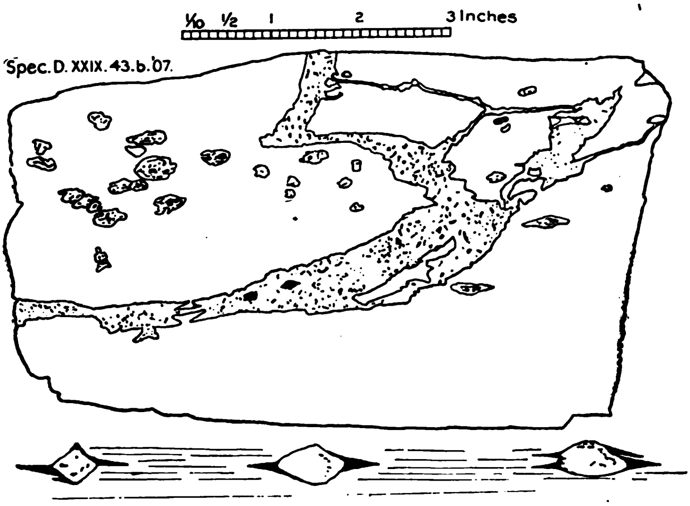


FIGURE 7.—Specimen of purplish-gray mica slate with minute dikes of pegmatite and lenses of apatitic granite, obtained near contact with granite at Anderson quarry, Barre, Vt. Cleavage parallel to length of block. At bottom several lenses (enlarged one-half) from other side of same specimen, showing biotite flanges and relation to cleavage.

[a] Vogt regards apatite in veins as having been formed by pneumatolytic agencies. Vogt, J. H. L., Ueber die durch pneumatolitische Processe an Granitgebundenen Mineral-neubildungen: Zeitschr. prakt. Geologie, 1894, p. 458; and Die Apatit-Ganggruppe: Idem, 1895, pp. 367, 444, 465. Barrell describes the occurrence of apatite in a banded hornstone at contact with granite. He attributes this apatitization to pneumatolytic impregnation. See Barrell, Joseph, Geology of Marysville mining district, Montana: Prof. Paper U. S. Geol. Survey No. 57, 1907, pp. 128, 130. For the formation of apatite at contact of diabase and granite, see Bull. U. S. Geol. Survey No. 354, p. 50.

with little beds of quartz-biotite schist spangled with biotite scales (0.2 inch long). These beds are crossed by large and minute dikes of pegmatite. Some of them, only 0.3 to 0.4 inch wide, run transverse to the bedding for a space and then subdivide to pass at right angles within one of the little beds. Small hand specimens combining both transverse and longitudinal dike courses can be obtained here. The aplite here has a matrix of quartz, oligoclase-albite, microcline, particles 0.25 to 0.1 millimeter, with porphyritic feldspar and quartz from 0.25 to 1 millimeter.

WOODBURY.

The contact of granite and schist is finely exposed on the northwest side of Robeson Mountain along the granite railroad. The axes of the schist folds strike N. 70° W. and pitch 30° S., while the axis of the hill runs about N. 70° E. The plane of contact appears to be about parallel to the strike. The schist is of two sorts. One is a dark, rather coarse biotite-muscovite-quartz schist with minute black particles and speckled with lenticular biotite plates (up to 0.75 by 0.25 millimeter) lying across the schistosity of the rock. Some plates have a nucleus of magnetite. There are also a few lenses of pyrite. The other sort, a thin bed of which touches the granite, is a dark, bluish-gray calcareous muscovitic quartzite abounding here with slender flattish six-sided prisms (up to 2 by 0.34 millimeters) of a light-colored hornblende. These are evidently the product of contact metamorphism. The granite sends little pegmatitic dikes into the schist. At the Webber quarry north of the mountain the capping is similarly injected.

All these contact phenomena lead to the following general inferences:

The 40-foot zone of fine-grained granite, with its three grades of texture, which intervenes between the coarse granite and the schist at Bethel, shows the effect of more rapid cooling upon texture. The material nearest the schist is glassy but that farthest away is coarsely crystalline. The semiliquid condition of the granite when it met the schist is shown by its having been molded by the delicate plications of the schist.

That the granitic intrusion at Barre was accomplished under great pressure is indicated by the intrusion of minute granitic dikes into such narrow transverse and longitudinal fissures in the schist and slate.

That the granitic intrusion at Barre was also attended by sufficient heat and moisture to inject the constituent elements of quartz, feldspar, biotite, pyrite, and apatite in vaporous condition into

the cleavage foliation of the slate is shown by the position and character of the lenses described. The formation of these lenses also affected the texture of the slate.

That at Woodbury the same causes sufficed to produce minute hornblende prisms within a calcareous quartzite along the granite contact.

ORBICULAR GRANITE.

The white quartz (muscovite-biotite) monzonite of Bethel is crossed on the east side of the Ellis quarry (see p. 113 and fig. 25) by a belt a few feet thick which has a marked flow structure consisting of vertical micaceous bands half an inch or less wide, a foot or more apart, and with a northerly strike. The micas in these bands tend to arrange themselves about the quartz and feldspar particles and are roughly parallel. Near the granite surface there is here a branching mass of wrinkled bronze-colored micaceous material a foot thick lying in the plane of flowage. Biotite appears to be the chief constituent in this mass. In thin section it consists of coarse stringers of an olive-greenish biotite, more or less completely surrounding particles of quartz and soda-lime feldspar. There are also small scales of muscovite penetrating the quartz and feldspar particles. In this same flowage belt there are crowds of elliptical discoid nodules of bronze-colored mica from 0.7 to 0.5 to 2 by 1.5 inches, and about 0.2 inch thick. The surfaces of these disks are either longitudinally or concentrically corrugated. While most of these nodules are discoid, some of the smaller ones are nut shaped, resembling those in the well-known butternut granite of Craftsbury and Northfield, Vt.[a]

Aside from their discoid form, the noticeable features of the Bethel nodules are that they lie in sheets parallel to the flow structure and that the major axes of the disks are parallel to the micaceous flowage bands. Plate II, *A*, is from a photograph of a hand specimen containing one of the larger disks.

The attention of geologists was first called to the nodular granite of Craftsbury ("Craftsbury pudding granite") by Hitchcock and Hager in 1861. It was next described by Hawes in 1878,[b] and in 1885 in greater detail by Chrusthov,[c] and again by the same geologist in an elaborate monograph in 1894.[d] He found that the nodules contained over twice as much calcite as the granite. As both the granite and nodules of Craftsbury differ from those of Bethel, his

[a] See Hitchcock and Hager, Report on the geology of Vermont, 1861, vol. 2, pp 563, 564, 721; also Dale, T. N., Bull. U S. Geol. Survey No. 275, 1906, p. 90; Perkins, G. H., Report state geologist of Vermont, 1906, p. 108, Pl. XXXII, fig. 2.

[b] Hawes, G., Geology of New Hampshire by C. H. Hitchcock, vol. 3, pt. 4, 1878, p. 203, pl. XI, fig. 4.

[c] Chrusthov, Konstantin Dmitrijevie, Note sur le granite variolitique de Craftsbury en Amérique: Bull. Soc. min. de France, 1885, vol. 8, pp. 132–141.

[d] Ueber holokrystalline makrovariolitische Gesteine: Mém. Acad. imp. des sciences de St. Pétersbourg, ser. 7, vol. 42, No. 3, 1894, Pudding granit von Craftsbury, Vt., pp. 132–146, pl. 2, fig. 9, and pl. 3, fig. 22.

inferences do not exactly apply to the Bethel nodules. But a conclusion of Frosterus from the study of a nodular granite in Finland applies well to that of Bethel, and shows the real significance of its nodules. It is that the nodules are basic segregations lying in a more basic part of the granite, indicating that the orbicular structure is simply a basic flowage band ("Schliere") and that the nodules themselves lie in this as still more basic segregations.[a]

The nodules in orbicular granite vary greatly in composition, size, and structure. Orbicular granites have been described from Bohemia, California, Corsica, Finland, France, Germany, Greece, Ireland, North Carolina, Norway, Ontario, Portugal, Rhode Island, Sardinia, Scotland, and Sweden. The literature of the subject is already large, embracing forty-six papers and probably more.[b]

DELIMONITIZATION ON THE UNDER SIDE OF SHEETS.

At the Frazer quarry on Blue Mountain, in Ryegate, there is a band of rusty stain or "sap" along the base of a sheet 12 feet thick which dips 25° SW. away from the mountain. Usually this limonitic stain affects the upper and lower parts of granite sheets for several inches from the sheet surface, but in this case the rusty band, which is only an inch thick, is separated from the lower sheet surface by an interval of 1 or 2 inches of clear granite. These rusty bands are due either to the oxidation of ferruginous minerals by clear water or to the deposition of limonite by ferruginous water—in both cases circulating between the sheet surfaces. (See, further, Bull. 354, pp. 35, 56.)

A careful examination of the specimen shows that all the minerals in the rusty band are stained a medium brown, and that the space below it, although of the same color as that above it, yet has dots 0.1 inch wide of very dark brown. A thin section of this part shows limonite proceeding from biotite and allanite crystals. A thin section of the clear granite above the band shows no limonite whatever about a crystal of allanite. There seems, therefore, to have been a partial delimonitization of the lower part of the zone of "sap," which may be attributed to organic acids in the water circulating between the sheets after that which produced the stain.

[a] Frosterus, Benj., Ueber ein neues Vorkomnis von Kugelgranit unfern Wirvik bei Borga in Finland, nebst Bemerkungen über ähnliche Bildungen: Tschermaks Min. pet. Mitt., Vienna, vol. 13, pt. 3, 1893, p. 187.

[b] See Zirkel, F., Lehrbuch der Petrographie, 2d ed., vol. 2, 1894, Kugelbildung, pp. 50, 51; also Rosenbusch, H., Mikroskopische Physiographie der Mineralien und Gesteine, 4th ed., vol. 2, 1907, Kugelstruktur, pp. 85–94.

PART II.—ECONOMIC DISCUSSION.

THE GRANITE RAILROADS.

The granite industry of Vermont owes no small part of its present prosperity to "granite railroads," which connect not only groups of quarries, but every quarry in each group with the main line, although these quarries are situated at considerable elevations and are inconveniently related to one another. Plate I shows the intricate character of the granite railroad about Millstone Hill near Barre; figure 8 gives a general idea of that connecting Robeson Mountain in Woodbury with Hardwick, and figure 24 that leading from Christian Hill to Bethel.

DESCRIPTION OF THE GRANITES AND QUARRIES.

CALEDONIA COUNTY.

The quarries of this county are in the towns of Hardwick, Kirby, Newark, Ryegate, and Groton.

HARDWICK.

Professor Perkins, in 1906, called attention to a fine light granite quarried in this town by the Northern Granite Company, from which stone more than 50 statuettes had been cut. He also mentioned granite quarries at Mackville, a mile east of Hardwick village, as then operated by the same company.[a] As none of these quarries were in operation in 1907 they were not visited by the writer.

The Buffalo Hill quarry is on Buffalo Hill about 2½ miles S. 60° W. from Hardwick village and about 500 feet above it. (See map, fig. 8.) Operator, Hardwick Granite Company, Hardwick, Vt.

The granite (specimen D, XXIX, 58, a and d), "dark-blue Hardwick," is a quartz monzonite of dark-gray shade, a little darker than "dark Barre" and a trifle lighter than "dark Quincy." Its texture is medium, with feldspars up to 0.3 inch and mica to 0.2 inch, generally even grained but with sparse, clear, porphyritic feldspars up to 0.4 inch, inclosing the feldspars, quartz, and mica. Its constituents, in descending order of abundance, are smoky quartz with hairlike crystals of rutile, with cavities in sheets parallel to rift cracks and

[a] See Perkins, George H., Report state geologist of Vermont, n. s. 5, 1906, p. 105.

with another shorter and rarer set at right angles to the first; milk-white soda-lime feldspar (oligoclase to oligoclase-andesine), much kaolinized, somewhat micacized and epidotized, and containing calcite; in about equal amount with this feldspar a clear to bluish-

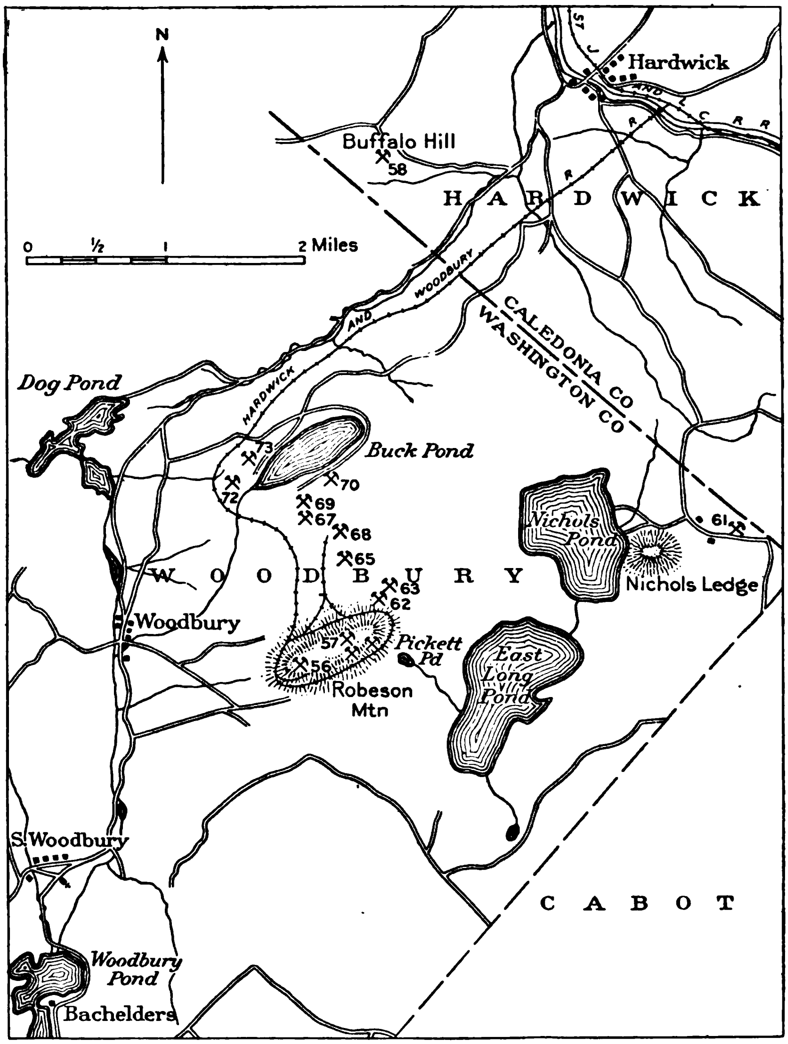


FIGURE 8.—Map compiled from various sources showing approximate locations of granite quarries in Woodbury, Washington County Vt. Quarries: 56, Fletcher; 57, Woodbury Granite Company; 61, Carter; 62, Carson; 63, Ainsworth; 65, Drenan; 67, Webber, new; 68, Webber, main; 69, 70, old quarries; 72, Leach; 73, Chase.

white potash feldspar (microcline with a little orthoclase), some of it kaolinized, some inclosing particles of all the other constituents; olive-colored biotite (black mica) with a little muscovite or bleached biotite. The accessory minerals are pyrite, magnetite, apatite,

zircon (crystals), and allanite; the secondary, kaolin, a white mica, epidote, and calcite. The soda-lime feldspar is radially intergrown with quartz.

The stone effervesces slightly with dilute muriatic acid.

An estimate of the mineral percentages by the Rosiwal method gives these results with a mesh of 0.4 inch and a total linear length of 38.8 inches.

Estimated mineral percentages in "dark-blue Hardwick" granite.

Feldspar	62.05
Quartz	21.75
Mica (biotite)	16.20
	100.00

The average diameter of all the particles by the same calculation in 0.093 inch; that of feldspar, 0.106 inch; of quartz, 0.122 inch; and of mica, 0.052 inch.

This is a bright stone with strong contrast between the white feldspar and black mica. It takes a fair polish, and hammers light with marked contrast to the polished face, which shows some pyrite and less magnetite.

The quarry, opened about 1887, is a small irregular opening 20 to 30 feet deep. It is a bowlder quarry without sheets. There are the following joint systems: (a), strike, N. 30° W., dip 35° W., spaced about 10 feet; (b), strike, N. 45° E., dip 40° NW., spaced about 10 feet; (c), strike, N. 25° W., dip 50° to 75° NE., spacing irregular. The rift is reported as vertical with N. 50° E. course, and the grain as about like joints (a), but neither is marked. There are some white, probably feldspathic, and black biotitic "streaks," really veins, with curving course. Rusty stain up to 6 inches thick appears on joint faces.

The plant consists of one horse derrick.

Transportation is by cart 2½ miles to Hardwick.

The product is used for monuments, particularly for polished and rock-faced work.

KIRBY.

The quarries are all on Kirby Mountain in the east part of the township and about 9 miles northeast of St. Johnsbury. (See map, fig. 9.)

GROUT QUARRY.

The Grout quarry is on the south side of Kirby Mountain in Kirby, 2½ to 3 miles N. 20° W. of North Concord and about 450 feet above the station there. (See fig. 9.) Operators, Carlton & Lake, East St. Johnsbury, Vt.

Grout quarry gray granite (specimen D, XXIX, 76, a) is a biotite granite of light to medium, slightly bluish-gray color and of medium inclining to fine, even-grained texture with feldspars up to 0.25 and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Clear to translucent potash feldspar (microcline, with inclusions of the other constituents, and also orthoclase); light smoky quartz with cavities in sheets with a set of ,cracks parallel to them; milk-white soda-lime feldspar (albite to oligoclase-albite) much kaolinized and with some white mica; biotite (black mica) and a little muscovite or bleached biotite. Zircon is an accessory mineral. Neither magnetite nor pyrite was detected. Secondary minerals are kaolin and a white mica. The granite does not effervesce in cold dilute muriatic acid.

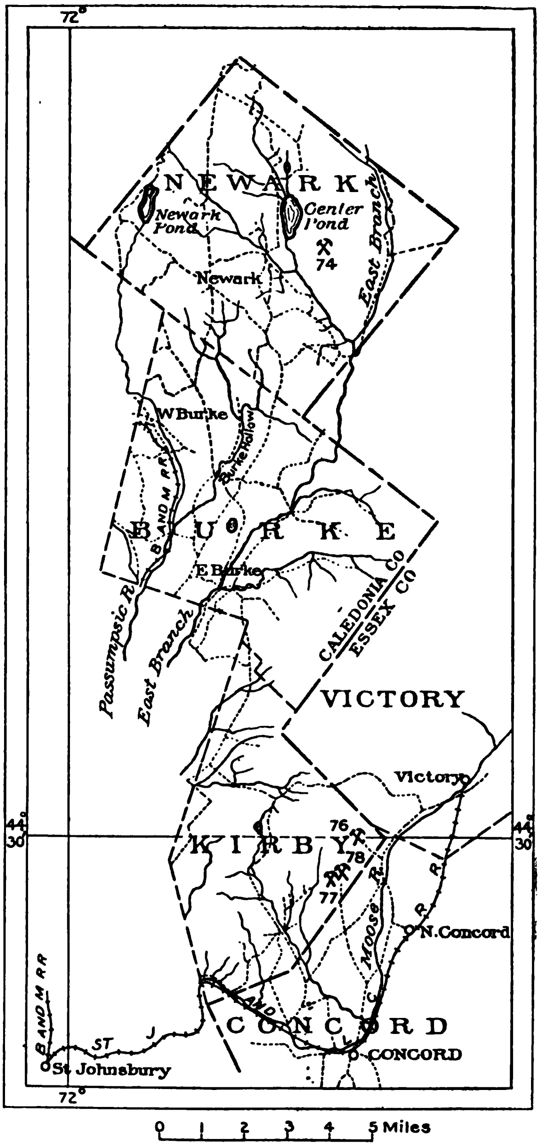


FIGURE 9.—Map of Kirby and Newark, from Beers's Atlas. 74, Bugbee; 76, Grout; 77, Kearney Hill; 78, Burke Granite Company.

This is a bright stone, but the fineness of its mica and the light shade of its quartz preclude strong contrasts.

The quarry, opened about 1899, consists of two openings, the northern and upper one 40 by 25 feet and 10 feet deep; the lower one 70 feet square and 3 to 5 feet deep.

The sheets, from 6 inches to 4 feet thick, but obscure in the upper opening, strike N. 55° E. and dip 25° SE. The joints are: (a), vertical, strike N. 25° W., spaced 1 foot to 2 feet 6 inches to 50 feet; (b) strike N. 85° E., dip 55° N., forming the south wall, spaced 6 to 8 feet; (c) strike N. 80° W., dip 40° N. 20° E., spaced 9 feet. The rift is reported as vertical, with N. 70° E. course, and grain as horizontal. The flow structure, consisting of streaks of biotite, is parallel to rift. There are some biotitic knots. A vertical quartz vein, half an inch thick, strikes N. 65° E. Rusty stain is confined to the surface and the thinnest sheets next to it.

Three aplite dikes strike N. 80° E. and are 6 feet 6 inches, 6 feet, and 1 foot thick. This aplite (specimen D, XXIX, $\overline{76}$, b) is dark gray and of very fine porphyritic texture. But few particles can be distinguished; feldspar 0.1 inch, mica 0.05 inch. It effervesces slightly with cold dilute muriatic acid. In thin section the particles of groundmass range from 0.037 to 0.148 millimeters, and consist, in descending order of abundance, of quartz, microcline (possibly also orthoclase), rare soda-lime feldspar, minute biotite scales, muscovite or bleached biotite, and secondary zoisite. The porphyritic particles and crystals are quartz, soda-lime feldspar, orthoclase, and biotite. One of the former feldspars has curved twinning planes, another is faulted across them, and has much secondary quartz about it, all indicating motion after crystallization. Calcite was not detected microscopically, but is present.

The plant consists of one horse derrick and one hand derrick.

Transportation is by cart 5 to 6 miles to rail at Concord.

The product is used for monuments.

KEARNEY HILL QUARRY.

The Kearney Hill quarry is on the west foot of Kirby Mountain, in Kirby, about 2¼ miles, roughly, N. 55° W. of North Concord. (See fig. 9.) It is operated by the Kearney Hill Quarry Company, Concord, Vt.

Gray granite of Kearney Hill (specimen D, XXIX, 77, a, b) is a quartz monzonite of light-gray shade with conspicuous fine black specks and medium inclining to coarse, generally even-grained texture, with feldspars up to 0.3 inch and mica to 0.2 inch, but with sparse porphyritic clear feldspars, embracing the other constituents, up to 0.5 inch. Its constituents, in descending order of abundance, are: Clear, colorless quartz with hairlike crystals of rutile and fluidal cavities in sheets; bluish to milk-white soda-lime feldspar (oligoclase), somewhat kaolinized and micacized, and inclosing much carbonate; some of it is intergrown with quartz in vermicular structure; clear potash feldspar (orthoclase and microcline, some of the orthoclase micacized); a large porphyritic orthoclase embracing all the other

constituents; biotite (black mica), some of it chloritized; and a little muscovite. The accessory minerals are pyrite, allanite, apatite, zircon, and rutile. The secondary are kaolin, a white mica, chlorite, and calcite. There is some effervescence with cold dilute muriatic acid.

Owing to the larger size of the biotite scales and the clearness of the quartz the contrasts are more marked than in the stone of the Grout quarry, and the sheen of the porphyritic feldspars on the rough face is marked.

The quarry, opened in 1906, measures about 100 by 35 feet and 5 feet in depth.

The sheets, from 1 to 3 feet thick, are horizontal or inclined 15° S. There is but one set of joints, which strikes N. 65° E. and is vertical, and is spaced 5 to 20 feet. The rift is reported as horizontal and the grain as vertical, with N. 20° W. course. Biotitic knots are up to 1.5 inches across. A "shake" structure extends down to 16 inches from the surface.

The plant consists of one hand derrick.

Transportation is by eart 5½ miles to a cutting firm and rail at Concord.

The product is used for monuments.

BURKE QUARRY.

The Burke quarry is on the west foot of Kirby Mountain, in Kirby, about 1,000 feet N. 60° E. from the Kearney Hill quarry, and about 2⅛ miles, roughly, N. 50° W. from North Concord. (See map, fig. 8.) Operator, Burke Granite Company (Incorporated), East Burke, Vt.

The granite (specimen D, XXIX, $\overline{78}$, a) is a quartz monzonite of light to medium gray shade, and of medium inclining to fine, even-grained texture, with feldspars up to 0.25 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with hairlike crystals of rutile, and sheets of cavities with cracks parallel to them; milk-white soda-lime feldspar (oligoclase) much kaolinized and micacized, with some carbonate and epidote, and in places intergrown with quartz in vermicular structure; clear to scarcely bluish potash feldspar (microcline with inclusions of oligoclase, quartz, and mica, also orthoclase micacized); biotite (black mica) some of it chloritized; and muscovite (white mica). Accessory minerals are very little magnetite, apatite, zircon, and rutile. Secondary minerals are kaolin, a white mica, epidote, zoisite, carbonate, and chlorite. There is no effervescence with cold dilute muriatic acid.

This stone closely resembles that of the Grout quarry in its shade and weakness of contrasts.

The quarry measures about 175 by 100 feet and from 10 to 20 feet in depth.

Between this and the Kearney Hill quarry there is an outcrop of schist, either an inclusion or the original schist capping, which strikes N. 15° E. The sheets, from 1 to 5 feet thick, dip 10° S. There are three sets of joints: Set (a), striking N. 25° to 30° W., dipping 30° W., forms the east wall, recurs 100 feet west, and has some parallel sub-joints; (b), discontinuous, strikes N. 5° W., dips 65° E. to 90°, and is spaced 100 feet; (c), discontinuous, strikes N. 75° E., is vertical, and is spaced 2 to 50 feet. The rift is reported as horizontal and marked, and the grain as vertical with N. 70° E. course. Biotitic knots are up to 2 inches across. There is little or no rusty stain below the top sheet.

The plant consists of a derrick and hoisting engine, an air compressor (capacity 100 to 200 cubic feet of air per minute), two large rock drills, and three air plug drills.

Transportation is by cart 5½ miles to rail at Concord.

The product is used for rough and cut monuments, and finds a market mostly in the West.

NEWARK.

The Bugbee, Alexander & Packer prospect is in the eastern part of Newark, on the west side of a ridge between Center Pond on the west and the East Branch of the Passumpsic on the east. This ridge lies north of Burke Mountain and southeast of Ball Hill. There is a marked east-west sag in the ridge. The prospect is a little north of the sag on a gently-sloping bench below the steeper part of the ridge and 363 feet above Center Pond, about east-southeast from its south end. (See map, fig. 9.) The intending operators are E. H. Bugbee and W. S. Alexander, of Barre, and H. D. Packer, of Newark, Vt.

The granite (specimen D, XXIX, 74, b), "Newark pink," is a biotite granite of light pinkish gray color and of coarse, even-grained texture, with feldspars up to 0.8 inch and mica to 0.15 inch. Its constituents, in descending order of abundance, are: Light pinkish gray potash feldspar (orthoclase and microcline), some of it intergrown with soda-lime feldspar or with inclusions of it, slightly kaolinized; medium smoky quartz with cavities in sheets; cream-colored, in places slightly greenish gray, striated soda-lime feldspar (albite to oligoclase-albite), much kaolinized, and with some white mica and carbonate; biotite (black mica), some of it chloritized. Accessory minerals are magnetite, pyrite, titanite, and allanite. Secondary minerals are kaolin, a white mica, epidote, and calcite.

An estimate of the mineral percentages by the Rosiwal method, with a mesh of 0.6 inch and total linear length of 46 inches, yields these results:

Estimated mineral percentages in granite at Newark.

Feldspar	64.80
Quartz	30.30
Mica	4.64
Magnetite	.26
	100.00

The average diameters of the particles obtained from the same calculation are: Feldspars (adding 20 per cent to the number as an estimate of the uncounted soda-lime particles), 0.162 inch; quartz, 0.106 inch; mica, 0.0406 inch. Average diameter of all particles, 0.123 inch.

The rock effervesces slightly with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.23 per cent of CaO (lime) soluble in warm dilute acetic acid (10 per cent), which indicates a content of 0.4 per cent of $CaCO_3$ (lime carbonate, calcite), the presence of which mineral is also shown by the microscope.

The contrasts in this granite are chiefly between the smoky quartz and the combined feldspars. It has very sparse porphyritic feldspars up to 1.5 by 0.5 inches, but these are hardly numerous enough to impart to it a technically porphyritic texture. The polished face shows magnetite in minute particles and very few of pyrite. The polish is fairly good, the mica particles, although somewhat large, not being very abundant.

The sheets on the steeper, higher part of the ridge 110 feet above the bench carrying the outcrop sampled, are from 3 to 6 feet thick and not far from horizontal. Joints (a) strike N. 30° E., dip 70° W.; (b) strike N. 5° W. and are vertical. The rift is possibly N. 85° E. and vertical. The granite for a thickness of 110 feet and presumably to the top of the ridge is the same as that described.

The nearest railroad is 8 miles away.

RYEGATE.

TOPOGRAPHY.

The Ryegate quarries are on the southwest and northeast sides of Blue Mountain, a ridge with a northwest-southeast trend situated about 5 miles west of Connecticut River in the east-central part of the town. (See maps, figs. 1 and 10.)

GENERAL GEOLOGY.

A mica schist crops out in the village of South Ryegate with a very steep dip, and appears to continue 3 miles north onto a bench on the southwest side of Blue Mountain and 770 to 800 feet above the village. The granite extends from the back or northeast part of the bench to the top of the ridge. At a point about 770 feet above the village the foliation and bedding of the schist strike N. 50° W. and dip 55° NE. In places the schist is coarse and speckled, but with it is interbedded a very quartzose mica slate (quartz-biotite-muscovite-epidote).

DESCRIPTION OF RYEGATE GRANITE.

The granites of Blue Mountain are quartz monzonites and biotite granites of light and medium more or less bluish gray color and of

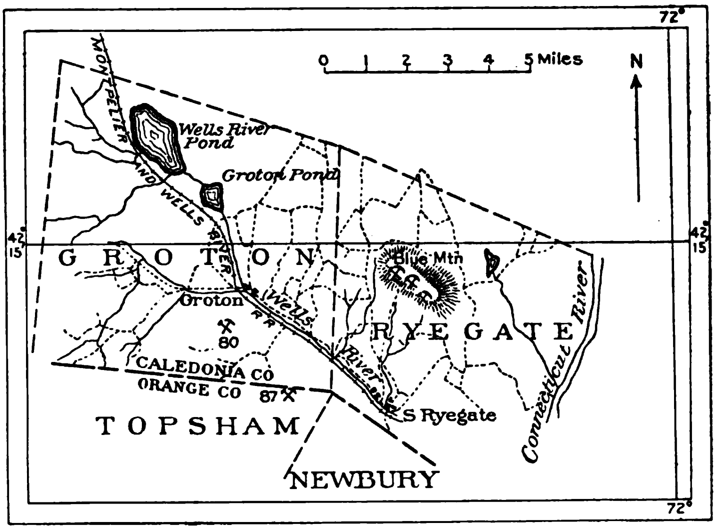


FIGURE 10.—Map of Ryegate, Groton, and part of Topsham, from Beers's Atlas. Quarries: 80, Benzie; 87, Ricker.

medium, very rarely fine to medium, even-grained texture, and are used chiefly for rough or hammered monuments. All the quartz monzonites of Ryegate ought to cut light.

GEOLOGY OF RYEGATE QUARRIES.

The inclusions of schist in "Ryegate granite" have already been described on page 19 and shown in Plate II, *B*, at the right. The sheets, ranging from 6 inches to 12 feet thick, are in places horizontal and in others dip from 5° to 25° S. 25°, 45°, 60° W., also gently S. and S. 45° E., on the southwest side of the mountain. Their relation to that slope of the mountain is apparent at the Frazer quarry and on the ridge northeast of the Italian quarry for some 300 feet above it; but at the Rosa quarry, on the other side of the axis of the ridge, the

sheets range from horizontal to 10° E., thus indicating a broad anticlinal sheet structure. There are four sets of joints or two sets, each with its complementary one. The strikes are N. 70° to 90° W., N. 5° E., N. 50° W., and N. 30° E. The flow structure, shown by biotitic streaks and planes, strikes N. 70° W., and dips 20° to 25° N. 20° E. The rift is reported as vertical with north-south or N. 55° E. course, and the grain as horizontal. A 22-inch basic dike crosses the granite on the northeast side with a N. 65° W. course. The granite for a foot on either side of it has subjoints one-half to 3 inches apart parallel to the dike. Small pegmatite dikes have N. 50° W. and N. 15° E. courses. The delimonitization of the rusty stain on underside of sheets has been noticed on page 26.

GIBSON QUARRY.

The Gibson quarry is on the southwest side of Blue Mountain, 940 feet above the village of South Ryegate. Operator, Ryegate Granite Works, South Ryegate, Vt.

The granite (specimen D, XXIX, 81, a, from upper sheets) is a quartz monzonite of light to medium gray shade and medium, even-grained texture with feldspars up to 0.4 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Very light smoky quartz with fluidal and other cavities in sheets and a set of cracks parallel thereto, also with traces of another set of sheets at right angles to these; milk-white soda-lime feldspar (oligoclase) slightly kaolinized with a little white mica and epidote, some of it intergrown with quartz in vermicular structure; bluish potash feldspar (microcline, also orthoclase) similarly intergrown; biotite (black mica) and a little muscovite or bleached biotite. Accessory, titanite, zircon crystals, apatite, and pyrite. Secondary, epidote, kaolin, and white mica.

The rock does not effervesce with cold dilute muriatic acid. Its contrasts are weak.

The quarry, opened in 1906, is about 200 feet square and from 2 to 4 feet deep.

The sheets, from 6 inches to 4 feet thick, dip 15° S. 25° W. and are normal. There is but one set of joints, which strike east-west, and are vertical, at irregular intervals, and discontinuous. The rift is reported as vertical north-south and the grain as horizontal. The flow structure (biotitic streaks) strikes N. 70° W. and dips 20° N. 20° E. A schist inclusion measures 12 by 8 inches. Small vertical pegmatite dikes strike N. 15° E.

The plant consists of a derrick, hoisting engine, two air compressors, a steam drill, and two air-plug drills.

Transportation is by cartage 3 miles to cutting sheds at South Ryegate, 940 feet lower.

The product is used for monuments and bases, and to some extent for building.

MORRISON QUARRY.

The Morrison quarry is on the southwest side of Blue Mountain, in Ryegate, about 940 feet above the village of South Ryegate and about 700 feet southeast of the Gibson quarry. Operators, D. A. Morrison & Co., South Ryegate, Vt.

The granite (specimen D, XXIX, $\overline{82}$, b) is a quartz monzonite of medium gray shade and medium, even-grained texture, with feldspars up to 0.4 inch and mica to 0.2 inch. Its constituents, in descending order of abundance, are: Very light smoky quartz with hair-like crystals of rutile and cavities in sheets in two rectangular directions and cracks parallel thereto; milk-white soda-lime feldspar (oligoclase), somewhat kaolinized, with some white mica and rarely epidote, also intergrown with quartz in vermicular structure; bluish potash feldspar (microcline and orthoclase), intergrown with quartz in the same way; biotite (black mica); and a little muscovite or bleached biotite. Accessory: Zircon, apatite, rutile. Secondary: Kaolin, epidote, a white mica, and calcite, as shown also by muriatic acid test.

This stone is identical with that of the Gibson quarry, but its contrasts are a little sharper, as the quarry had got down to thicker sheets. Although the contrasts are feeble the smoky quartz is somewhat conspicuous.

The quarry, opened in 1900, measures about 400 by 200 feet, with an average depth of 20 feet.

The sheets, from 1 to 5 feet thick, dip very gently south and southeast. There are two sets of joints: (a), striking N. 85° E., dipping 70° S., forms a heading on the north side; (b), striking N. 30° E., dipping 75° N. 30° W., is discontinuous and spaced very irregularly. The rift is reported as vertical north-south, and the grain as horizontal. Schist inclusions measuring 3 feet by 1 foot and 8 by 4 feet are described on pages 19, 20. (See also Pl. II, *B*, at the right.) Small pegmatite veins, "tight sets," are bordered with large biotitic spots and muscovite flakes.

The plant consists of two horse derricks.

Transportation is by cartage 3 miles to South Ryegate, 940 feet lower.

The product is used for bases and hammered monuments.

ITALIAN QUARRY.

The Italian quarry is on the southwest side of Blue Mountain, 940 feet above the village of South Ryegate and about 400 feet N. 60° W. from the Gibson quarry. Operator, Caledonia Quarry Company, South Ryegate, Vt.

The granite is a quartz monzonite of light to medium gray shade and medium, even-grained texture, identical with that of the Morrison and Gibson quarries.

The quarry, opened in May, 1907, measures about 250 by 100 feet and from 1 to 5 feet in depth.

The sheets, from 10 inches to 5 feet thick, dip 20° W. Only one set of joints, which strikes N. 50° W. and dips 30° E., and is spaced 50 feet. The rift is reported as vertical with N. 55° E. course and the grain as horizontal, and both as equal. Two pegmatite dikes (0.25 and 2.5 inches thick) strike N. 50° W. and dip 45° N. 50° E. There is a biotitic segregation 3 inches by 1 inch. There is little or no rusty stain on sheet surfaces.

The plant consists of one horse derrick.

The product is carted 3 miles to South Ryegate, and is used for bases and hammered monuments.

TUPPER QUARRY.

The Tupper quarry is on the southwest side of Blue Mountain, about 600 feet S. 20° E. of the Italian quarry and from 940 to 960 feet above South Ryegate. Operators, W. S. Tupper & Co., South Ryegate.

The granite is a quartz monzonite of light to medium gray shade and medium texture, identical with that of the Morrison, Gibson, and Italian quarries.

The quarry, opened in May, 1907, measures about 100 by 50 feet and 3 feet in depth.

The sheets, from 1 to 3 feet thick, dip 5° S. 60° W. There is only one joint, which strikes N. 40° W. and dips 35° S. 40° E. Little pegmatite dikes up to 0.75 inch wide occur at irregular intervals, striking N. 50° W. and dipping 30° N. 50° E.

There is a compressive east-west strain.

The plant comprises one horse derrick.

Transportation is by cartage 3 miles to South Ryegate, 950 feet lower.

The product is used for bases and hammered monuments.

ROSA QUARRY.

The Rosa quarry is on the northeast side of a southeast spur of Blue Mountain, which is about 300 feet below its top and in line with its main axis. This quarry is about one-third mile by road from the Frazer quarry and about 1,100 feet above South Ryegate. Operator, Vermont Gray Granite Company, South Ryegate, Vt.

The granite is of two kinds. The first is fine gray (specimen D, XXIX, $\overline{79}$, a), a biotite granite of medium gray shade and of fine inclining to medium, even-grained texture, with feldspars up to

0.2 inch and mica to 0.1 inch. Its general shade is a trifle darker than that of the quartz monzonite of the Morrison quarry. Its constituents, in descending order of abundance, are translucent to very light bluish gray potash feldspar (orthoclase and microcline); light smoky quartz with hair-like crystals of rutile, and fluidal and other cavities in sheets with cracks parallel thereto; whitish soda-lime feldspar (oligoclase) slightly kaolinized, micacized, and epidotized, in places intergrown with quartz in vermicular structure; biotite (black mica), a little muscovite or bleached biotite. Accessory: Apatite, zircon crystals, titanite. Secondary: Kaolin, a white mica, epidote, limonite.

W. T. Schaller, chemist, of the United States Geological Survey, finds that this stone contains 0.03 per cent of CaO (lime) soluble in warm dilute (10 per cent) acetic acid, which indicates the presence of 0.05 per cent of $CaCO_3$ (lime carbonate). No carbonate was detected in thin section nor any effervescence with cold dilute muriatic acid.

The fineness of the texture of this stone precludes mineral contrasts.

The other granite (specimen D, XXIX, $\overline{79}$, b), "coarse gray," is a biotite granite of medium bluish-gray shade, and medium, even-grained texture, with feldspars up to 0.3 inch and mica to 0.15 inch. This is also a trifle darker than that of the Morrison quarry. Its constituents, in descending order of abundance, are: Translucent bluish-gray potash feldspar (microcline and orthoclase); light smoky quartz with fluidal and other cavities in sheets, with cracks parallel to or coinciding with them; milk-white soda-lime feldspar (oligoclase) somewhat kaolinized, a little micacized, with some carbonate and less epidote; biotite (black mica), some of it bleached. Accessory: Apatite in slender prisms, allanite. Secondary: Kaolin, calcite, white mica, epidote. The stone effervesces with cold dilute muriatic acid.

Its contrasts are stronger than those of the quartz monzonites of the Morrison and Gibson quarries. It contains more biotite.

The quarry, opened in 1906, measures about 150 by 75 feet and from 10 to 25 feet in depth.

The sheets, from 1 to 10 feet thick, are horizontal or dip to 10° E. There are three sets of joints: (a), striking east-west, dipping 65° S., forms a 3-foot-wide heading on the north; (b), striking N. 70° to 80° W., dipping 40° N. 10° to 20° E., is spaced 1 to 25 feet, coated with epidote and slickensided; (c), striking N. 5° E., vertical, one only. The rift is reported as vertical with N. 60° E. course, and the grain as horizontal. The fine granite (specimen $\overline{79}$, a) occurs only north of heading (a). On the south edge of the quarry a vertical basic dike, 22 inches thick, strikes N. 65° E. (See page 36.) Rusty stain does not exceed 2 inches. In a surface sheet it measures an inch.

The plant includes, at the quarry, a 45-ton derrick, a hoisting engine, a small air compressor for two air plug drills, a large steam rock drill, and a steam pump, besides at the cutting shed a hand derrick and a 10-ton overhead crane.

The product is carted nearly 4 miles to the cutting shed at South Ryegate, and is used for hammered and rock-faced monuments and bases.

FRAZER QUARRY.

The Frazer quarry (formerly known as Hall's) is on the southwest side of the southeast spur of Blue Mountain, about 950 feet above South Ryegate. It was not in operation in 1907. The owner is Mrs. Margaret Hinchey, Hydeville, Vt.

The granite (specimen D, XXIX, $\overline{85}$, b), gray granite, is a quartz monzonite of light to medium gray shade and of medium inclining to coarse, even-grained texture, with feldspars up to 0.4 inch and mica to 0.2 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with hair-like crystals of rutile and cavities in sheets, with a set of cracks parallel to them; milk-white soda-lime feldspar (oligoclase) somewhat kaolinized, with some small plates of white mica and a few grains of epidote. In places it is intergrown with quartz in vermicular structure; translucent bluish potash feldspar (microcline), some of it slightly kaolinized; biotite (black mica) and a little muscovite. Accessory: Titanite, allanite, apatite, zircon. Secondary: Kaolin, a white mica, epidote, and carbonate shown by slight effervescence with cold dilute muriatic acid.

While the general shade of this stone differs but little from that of the Morrison and Gibson quarries, the contrasts between its minerals are much more marked.

The quarry measures about 300 feet square and from 5 to 20 feet in depth.

The sheets are normal and from 1 to 12 feet thick, dipping 25° SW. There is but one joint (southwest side), striking N. 70° W., dipping 35° N. 20° E. A flow structure of biotitic streaks and sheets strikes N. 70° W., and dips 45° N. 20° E. In the west half of quarry this is so prominent as probably to detract from the value of the stone. Rusty stain along sheet surfaces is up to 3 inches thick. (See, further, p. 26.)

The plant comprises two horse derricks.

The product must be carted 3½ miles to South Ryegate.

GROTON.

The Benzie quarry is in Groton about a mile S. 25° W. from the Wells River Bridge at Groton and 300 feet above it, and about 4½ miles S. 85° W. from Blue Mountain in Ryegate. (See fig. 10.) Operators, McCrae, Benzie & Co., Groton, Vt.

The granite (specimen D, XXIX, $\overline{80}$, a), "Vermont blue," is a quartz monzonite of medium, very bluish gray color and even-grained medium inclining to fine texture. Its constituents, in descending order of abundance, are: Clear, colorless to very light smoky or very light bluish quartz, with few cavities and brightly polarizing rift and grain cracks; light-bluish translucent soda-lime feldspar (oligoclase), somewhat kaolinized and with white fibrous mica, also a white mica in small scales, and some calcite; a little clear potash feldspar (microcline, also orthoclase), with inclusions of oligoclase, quartz, and biotite; biotite (black mica); and a little muscovite or bleached biotite. Some of the feldspars are minutely intergrown with quartz in vermicular structure. Accessory: Titanite, pyrite, zircon crystals, apatite, allanite. Secondary: Kaolin, a white mica, calcite, leucoxene. The granite effervesces with cold dilute muriatic acid.

This stone is brilliant and markedly bluish, but its mineral contrasts are feeble owing to fineness of texture and similarity in shade of feldspar and quartz.

The quarry, opened in 1896, measures about 200 by 175 feet and from 40 to 60 feet in depth.

The sheets are normal, from 1 to 10 feet thick, and range from the horizontal to a very low dip north and also east. There are three sets of joints: (A), striking N. 55° E. and vertical, spaced 15 to 50 feet, forms a rusty heading on the west wall, with short vertical subjoints at right angles to it; (B), striking N. 50° E. (diagonal to quarry), dipping 60° S. 50° E., discontinuous and at irregular intervals; (C), striking N. 20° W. and vertical, discontinuous and rare. The rift is reported as horizontal and the grain as vertical, with N. 55° E. course. There is a coarse "shake" structure in bands up to a foot thick parallel to the sheets, at points 25, 40, and 60 feet below the surface.[a] There are biotitic masses on the west side parallel to joints (A), the course of which is also that of the grain, and thus also that of the flow. On the west wall is a dike of quartz monzonite (specimen D, XXIX, $\overline{80}$, b) 5 feet thick, of medium bluish-gray color and very fine, even-grained texture, with feldspars up to 0.1 and mica mostly under 0.05, exceptionally 0.1 inch. Its constituents are the same as those of the main granite. There are two dikes of similar quartz monzonite but of dark, slightly bluish-gray color and extremely fine texture, with feldspars up to 0.06 (exceptionally 0.1) and mica to 0.04 inch. These dikes are 6 and 2 inches thick, strike N. 5° and 20° E., and dip 70° E. and 90°. Several pegmatite dikes from 1 to 6 inches thick cross the entire quarry, cutting the first granite dike, some striking N. 17° W., others in various directions. There is also a 3-inch diabase dike on the west wall. It contains porphyritic augite

[a] See glossary (p. 132); also Bull. U. S. Geol. Survey No. 354, p. 31.

crystals, some of which have been replaced by quartz or calcite or chlorite. These structural features are shown in diagram in figure 11. A compressive strain is reported here as from all directions. Rusty stain is only an inch thick on sheets 10 feet below the surface.

The plant at the quarry consists of a 50-ton derrick, hoisting engine, steam pump, and large rock drill, to which were added in 1908 a 90-foot derrick and an air compressor with a capacity of 130 cubic feet of air per minute, sufficient for two large rock drills and four air-plug drills. At the cutting shed there are two hand derricks, two steam derricks, an air compressor, two surfacers, 20 air hand tools, two steam engines, and three polishers.

The product is carted 1½ miles to the cutting shed at Groton. It is used for monuments and buildings. The fine stone of the granite dike is used for special orders and carved work. Examples are the Davison monument at Woodsville, N. H., and the Dr. S. N. Eastman monument at Groton, Vt.

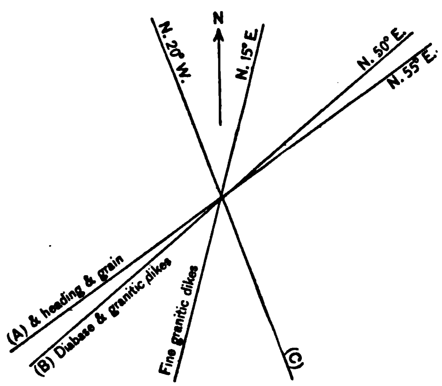


FIGURE 11.—Structure at Benzie quarry, Groton.

ORANGE COUNTY.

The quarries of Orange County are in Williamstown, but as these closely adjoin those of Barre, as shown on the map (Pl. I), they will be considered in connection with the Barre quarries. (See pp. 85–87.) A quarry in Topsham and a prospect in Randolph properly belong here.

TOPSHAM.

Granite was formerly quarried at two points in Topsham. One was very near the village of South Ryegate, the other on Pine Mountain about south-southeast of Groton.[a] Hitchcock and Hager's geologic map represents a granite area extending from Groton into Topsham, but it seems too far west. (See map, fig. 10.)

The Ricker quarry is in Topsham at the west foot of Pine Mountain, roughly about 5½ miles west-southwest of Blue Mountain, 2¼ miles southeast of the Benzie quarry, and 2¾ miles south-southeast of Groton and 490 feet above it. (See fig. 10.) Owner is Isaac N. Ricker, Groton, Vt.

The granite (specimen D, XXIX, $\overline{87}$, a), "Pine Mountain," is a quartz monzonite of medium bluish-gray color and medium, some-

[a] This last, here described, is probably the one referred to by the state geologist in 1900 as operated then by the Pine Mountain Granite Company. (See Perkins, G. H., Mineral resources of Vermont, 1899–1900, p. 75.)

what even-grained texture with feldspar up to 0.4 inch and mica to 0.1 inch, but with sparse, clear, porphyritic feldspars, including all the other chief constituents. The stone is not quite so bluish as that of the Benzie quarry in Groton, nor do its feldspars seem to be as evenly distributed. Its constituents, in descending order of abundance, are clear colorless to very pale smoky quartz with cavities in intersecting sheets; bluish translucent to milk-white soda-lime feldspar (oligoclase) somewhat kaolinized and micacized, and with calcite; clear potash feldspar (microcline and orthoclase) inclosing oligoclase, quartz, and biotite; biotite (black mica); and a little muscovite or bleached biotite. Accessory: Titanite, allanite, apatite, zircon. Secondary: Kaolin, a white mica, calcite, zoisite. There is some intergrowth of feldspar and quartz. The stone effervesces with cold dilute muriatic acid.

The porphyritic clear feldspars enhance the brilliancy of the rough surface. Its contrasts are greater than those of the Benzie quarry stone, but there are minute rust spots on the long-exposed blocks about the quarry, the cause of which was not manifest.

The quarry is about 40 by 32 feet and the working face on the east is 20 feet high from the road and quarry level. It has been idle a number of years.

The sheets, from 5 to 12 feet thick at their widest parts, are normal and horizontal or inclined as high as 10° N. 45° W. There are two sets of joints: (a), striking N. 70° E., vertical, forms the north wall, and a 25-foot heading north of it with joints 2 to 4 feet apart, and another on the south wall; (b), striking N. 40° E. and dipping 55° N. 45° W., forms the east wall and recurs 10 feet east. The flow structure has a N. 35° E. course. Vertical pegmatite dikes up to 1.5 inches thick strike N. 25° W. Aplite dikes up to 1 inch thick strike N. 45° and 55° E.

The product was carted about 3 miles to rail at Groton, 490 feet lower.

RANDOLPH.

Beedle's prospect is in the west corner of the town of Randolph between the Bethel line and the west branch of White River, in school district 11, three-fourths of a mile west and southwest of the Vermont Central Railroad, which here describes a curve. It is on the farm of A. H. Beedle, of Randolph, Vt. (See fig. 24.) The particulars were obtained by Professor Perkins.

According to the state geologic map of 1861 this granite should be on the west side of the western belt of "clay slate," but no granite is shown on the map in this town.

The granite (specimen D, XXIX, 100, a, and b), fine white granite, is a quartz monzonite of extremely light gray shade without any mica spots. It is lighter than "Dummerston white" but not as

white as that of Bethel when the rough faces are compared, and its slight grayness has a tinge of green in it. Its texture is even-grained and fine with feldspars nearly all under 0.1 inch and none over 0.15 inch. Its constituents, in descending order of abundance, are: Milk-white striated soda-lime feldspar (albite to oligoclase-albite), some of it intergrown with potash feldspar (microcline), the latter forming, however, but a small portion of the particle (the soda-lime feldspar is more or less kaolinized and micacized); colorless, clear quartz with fluidal and other cavities, rarely with hairlike crystals of rutile; very little separate potash feldspar (microcline) in minor particles; muscovite (white mica) in scales up to 0.37 millimeter. The accessory minerals are zircon, apatite, and rutile. No magnetite or pyrite was detected. The secondary minerals are kaolin, a white mica, rather abundant epidote, and zoisite in irregular particles up to 0.5 millimeter, exceptionally 0.75 millimeter, accounting for the greenish tinge (this is really the fifth mineral in order of abundance); a little calcite and rare chlorite scales up to 0.22, exceptionally 0.75 millimeter, reenforcing the greenish tinge.

An estimate of the mineral percentages made by applying the Rosiwal method to a camera lucida drawing of a thin section enlarged 40 diameters yields these results with a mesh of 1 inch and a total linear length of 34 inches.

Estimated mineral percentages in fine white granite of Randolph.

Feldspar	76.5
Quartz	21.2
Mica	2.3
	100.0

The average diameter of the particles obtained from the same calculation is 0.0049 inch; that of the feldspar, 0.0083 inch; of the quartz, 0.0032 inch; and of the mica, 0.0024 inch.

The stone effervesces slightly with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.37 per cent of CaO (lime) soluble in warm dilute (10 per cent) acetic acid, which indicates a content of 0.66 per cent of $CaCO_3$ (lime carbonate, calcite) which mineral also appears in thin section.

The stone takes a high polish, as the absence of all but very minute mica plates implies. Being a quartz monzonite, and being also free from mica spots, it will probably hammer quite as white as the quartz monzonite from Bethel. The hand specimens show traces of rift or flow structure.

There are no data as to size of outcrop or as to structure. The principal opening is 60 by 30 feet.

ORLEANS COUNTY.

NEWPORT GRANITE COMPANY'S QUARRY.

The Newport Granite Company's quarry is near the center of the town of Derby and about 4 miles roughly east of the city of Newport, on Lake Memphremagog. (See map, fig. 1.) Operator, George R. Farquharson, Newport, Vt.

The granite (specimen D, XXIX, 75, a), gray granite, is a quartz monzonite, with both biotite and muscovite, of light bluish-gray color and even-grained, medium inclined to fine texture with feldspars up to 0.25 and 0.3 inch, and mica to 0.15 inch. Its constituents, in descending order of abundance, are: Light smoky quartz with hairlike crystals of rutile, fluidal and other cavities in sheets with cracks parallel to and in places coinciding with them; clear to bluish milk-white striated soda-lime feldspar (oligoclase), mostly much kaolinized and somewhat micacized, also intergrown in places with quartz in vermicular structure; clear to translucent bluish potash feldspar (microcline and orthoclase) slightly kaolinized; biotite (black mica); muscovite (white mica). Accessory: Apatite, titanite, allanite, rutile. No magnetite or pyrite was detected. Secondary: kaolin, a white mica, and calcite from chemical test.

There is no effervescence with cold dilute muriatic acid, but W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.05 per cent of CaO (lime) soluble in warm, dilute (10 per cent) acetic acid, which indicates the presence of nearly 0.09 per cent of $CaCO_3$ (lime carbonate, calcite), which is very slight indeed.

The shade of this stone is between that of "light Barre" and that of the granite of Hallowell, Me. It has more black mica than "light Barre" and stronger contrasts. These are bright between the black mica, the feldspar, and an intermediate shade formed by the muscovite and quartz together. The stone should hammer lighter than a biotite-muscovite granite.[a]

The quarry, opened about 1880, measures about 300 feet N. 45° W. by 250 feet N. 55° E, and averages 20 feet in depth.

The sheets, from 3 to 18 feet thick, dip 20° S. 55° W. They "grow together," that is, sheet structure is undeveloped in the western part of the quarry, making masses 22 to 25 feet thick. One set of vertical joints, discontinuous, strikes N. 55° W., is spaced 10, 30, and 100 feet and forms a heading on the north wall. At the northeast corner there is a trace of a transverse set. The rift is reported as horizontal and the grain as vertical with N. 55° E. course. Both are marked. Flow structure, consisting of muscovitic and biotitic bands, is vertical with N. 50° E. course. The muscovite scales in these bands

[a] See a recent reference to this stone and quarry in Richardson, C. H., The geology of Newport, Troy, and Coventry: Rept. State Geologist of Vermont, 1908, p. 280, and Pl. LVIII.

measure up to 0.25 inch. There are very irregular biotitic surfaces in the eastern part of quarry, resembling tree roots in form. Associated with them are nonmicaceous lighter tortuous bands. These are presumably irregularities in the flow structure. A "shake structure" up to 5 inches thick occurs on some sheet surfaces, and the rock there is passing into sand. The contact here has already been alluded to on page 13. A north-south compressive strain is reported by the foreman. There is no "sap" on the sheet surfaces.

The plant consists of one 40-ton and two 20-ton derricks, three hoisting engines, an air compressor (capacity 292 cubic feet of air per minute), four large rock drills, fifteen air plug drills, and three steam pumps.

The product is carted 4 miles to the railroad at Newport. It is used for monuments and buildings, and finds its chief market in the West. Specimen: The prison ship martyrs' monument in Fort Greene Park, Brooklyn, N. Y. Height, 150 feet, shaft 18 feet in diameter at base and 14 feet at top.

PARMENTER QUARRY.

The Parmenter quarry, visited in 1909, is in Derby Township, near Beebe Plain, close to the Canada line and about a mile east of Lake Memphremagog. It is not shown on figure 1. Operator, W. H. Parmenter, North Derby, Vt.

The granite (specimen D. XXX, 72, a), light granite, not examined microscopically, is either a biotite granite or a biotite-quartz monzonite of very light gray shade and even-grained medium texture, with feldspars up to 0.3 and micas to 0.2 inch. Its constituents are slightly bluish milk-white feldspars, light-smoky quartz, and biotite (black mica). It effervesces slightly with acid test.

The general shade of this granite is lighter than that of North Jay and darker than that of Bethel, or nearly the same as that of "West Dummerston white" but with more conspicuous black micas.

The quarry, recently opened, is 40 by 25 feet in area and 10 feet deep.

The sheets, 2 to 5 feet thick, are insufficiently exposed but appear to undulate horizontally. Joints (a) strike N. 50° W, dip 60° SW., are spaced 10 to over 20 feet. Joints (b) strike N. 30° E., dip 80° S. 60° E., one only. The rift is reported as horizontal and grain vertical with N. 50° E. course. In a larger quarry on the Canadian side, a few hundred feet from the other, worked by the same operator, granite of the same mass and character has sheets 10 feet thick and a flow structure with N. 60° W. course.

The plant consists of one hand derrick.

The product is carted half a mile to a siding on the Canadian Pacific Railway at North Derby and is used for hammered monuments or bases.

WASHINGTON COUNTY.

The quarries are in Barre, Cabot, Calais, and Woodbury. Those of Williamstown, in Orange County, will be described in connection with those of Barre, as they belong to the same group and their granite is continuous and identical.

BARRE AND WILLIAMSTOWN.

TOPOGRAPHY.

The city of Barre lies about 5 miles southeast of Montpelier (see fig. 1), and the Barre quarries are 3 miles farther southeast, near the southeast corner of the township of Barre, and a few of them are in Williamstown, in Orange County, which adjoins Barre on the south. The city of Barre lies on Stephens Brook, a tributary of the Winooski, which empties into Lake Champlain. About half a mile south-

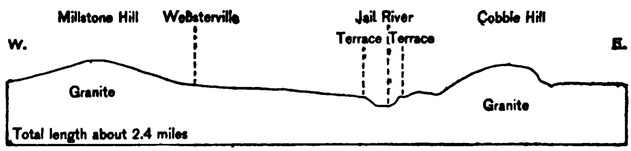


FIGURE 12.—General topographic section through granite mass of Barre. Scale, 194 feet to 0.1 inch

southeast of Barre City this brook receives a tributary from the southeast, known as Jail River. Some 2½ miles southeast of the city this river flows through a canyon-like gorge between flat-topped masses of sand, clay, and bowlders over 200 feet thick. A little north of Jail River at this point a roundish granite mass, known as Cobble Hill, rises to a height of 1,100 feet, by aneroid, above the city; and 2 miles about southwest of this hill and a little south of the river another granite mass, known as Millstone Hill, rises to a height of 1,200 feet, by aneroid, above the city. Fifty-six quarries are grouped about these two granite masses, and of these 52 are about Millstone Hill. The section (fig. 12) will serve to convey a general idea of the surface features described. The locations and designations of the Millstone Hill quarries are given in Plate I.

GENERAL GEOLOGY.

The geology of the granite area of Barre was last treated by George I. Finlay.[a]

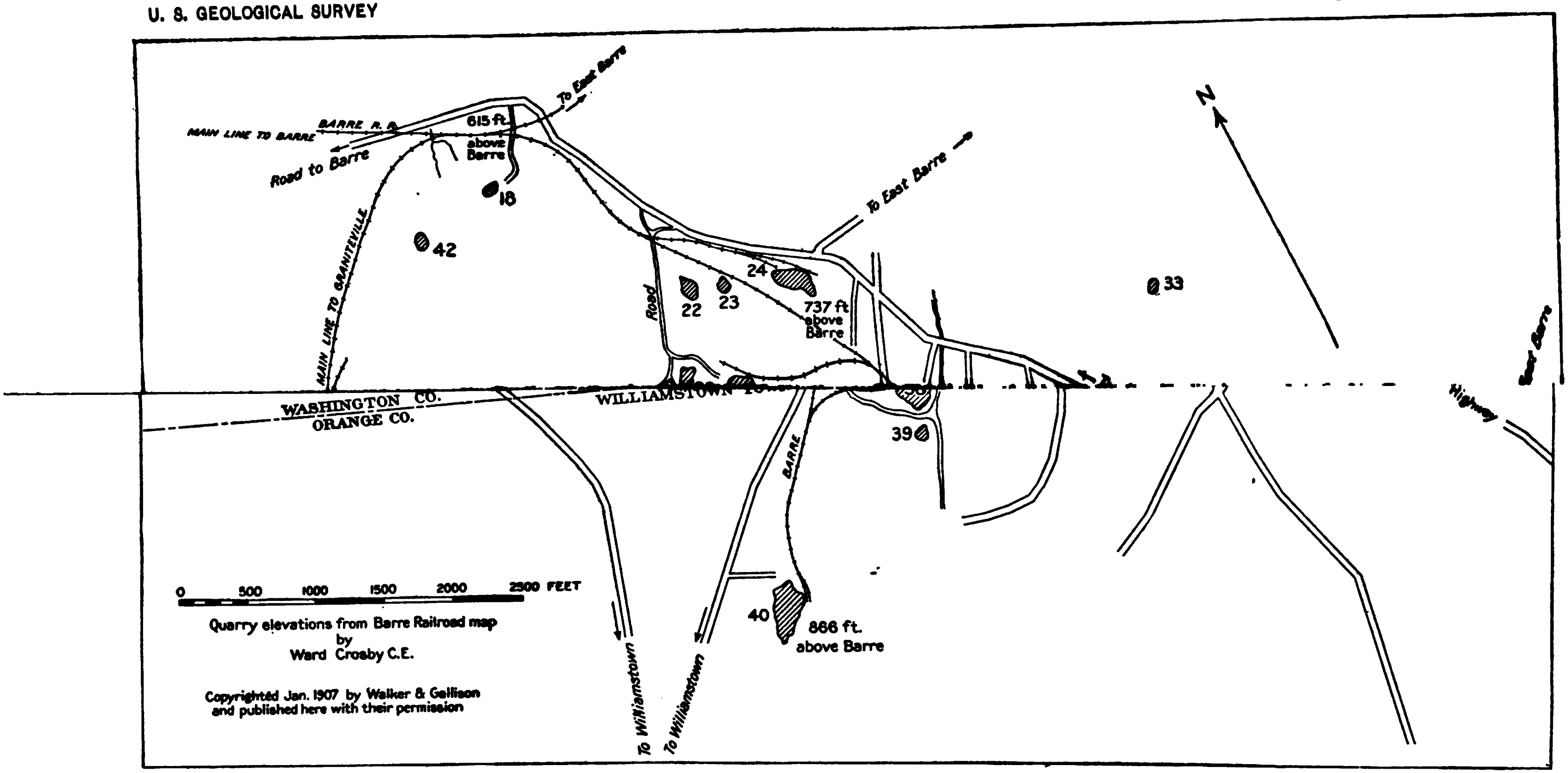
[a] The granite area of Barre, Vt.: Rept. Vermont State Geologist (3), 1902, pp. 46–59, and Pl. IV.

His map shows that he regards the two granite hills as parts of one granite area with a north-northeast trend over 4 miles long by 1½ wide, surrounded by slate and schist. Its representation on the state geologic map of 1861 is not far different. The writer's time was too short to enable him to trace the boundaries of the granite and schist, nor was a map suitable for such purpose available. Finlay represents a schist tongue crossing Millstone Hill diagonally from northwest to southeast, and Cobble Hill as all granite, but the writer found schist on the north side of the top of the Cobble, without, however, determining its northern limit. The schist capping also crops out at Jones Brothers' and Barclay's quarries, and near the Marr & Gordon quarry of the Consolidated Company (Nos. 10, 12, 26 in Pl. I), and in Websterville. Some of these schist masses are probably lesser bands still lying on the Granite, which Finlay states were too small to enter on his small-scale map. The strike of the foliation of the schist about the quarries varies from N. to N. 60° E., and the dip is steep west or 90°. In a group of quarries south-southeast of Millstone Hill it strikes uniformly from N. 30° to 35° E.

These are the chief geologic features of the Barre district. Four formations are represented: (1) The schist, a metamorphosed marine argillaceous and calcareous sediment of unknown thickness, underlying the city and surrounding the granite area; (2) the granite, of igneous origin, intruded in the schist and forming two domes, 2 miles apart, with an intervening depression, which in consequence of the erosion of the schist now project through it; (3) certain dark basic dikes of later date cutting the granite and the schist also; (4) finally, masses of sand, clay, and bowlders, over 200 feet thick in the hollow between the domes, of glacial origin, overlying the schist and part of the granite.

The geologic age of schist and granite have been discussed on page 13, and their probable history was sketched on page 16.

As many as seven different sets of surface forms have existed here: (1) The original surface of the sediments of clay and sand before their emergence from the sea; (2) the surface of those sediments after their metamorphism into schist and before the granitic intrusion; (3) the surface of the schist mass as modified by the granitic intrusion; (4) the surface of the schist and granite masses which resulted from the long period of preglacial erosion; (5) the original surface of the superimposed glacial deposits; (6) the surface of the glacial deposits as modified by glacial lake levels; (7) the surfaces produced in both unmodified and modified glacial deposits by post-glacial streams. It is assumed in this outline that any modifications of the eroded rock surface by the glacier were unimportant, and the surface of the ice sheet itself has not been considered.



MAP OF THE "BARRE QUARRIES" ABOUT MILLSTONE HILL, IN BARRE AND WILLIAMSTOWN, VT.

The present surface is evidently of complex origin. Parts of it were formed under (4), (5), (6), and (7). Wherever no glacial deposits were formed or wherever they were afterward removed we have the surface (4). In the gorge between Millstone and Cobble Hills, as shown in figure 12, the coarse and fine glacial deposits have a nearly level surface, which is probably due to terracing by a glacial lake (6). These opposite terraces may have been continuous, but the gorge itself is partly or entirely the result of the cutting of the terraced glacial deposits (7). In places the processes of (7) have exposed the schist surface formed by (5) and made small inroads upon it.

The schist of Barre varies much in character. A few observations were made and specimens collected. In many places it contains lenses and beds of calcareous quartzose rock. On Brook avenue, in the northwest part of the city, a mass of this dips 30° to 40° about southwest, but with traces of plicated bedding in the opposite direction. It is a very dark gray fine-grained *quartzose crystalline limestone.* The sections show quartz particles to 0.24 millimeter in a cement of calcite plates with rare muscovite scales and many minute black (carbonaceous?) particles. At the other end of the city near the covered bridge over Jail River it is a very fine black roofing slate with minute secondary plications, and spangled with black tabular crystals up to 0.1 inch across, probably of ilmenite. The microscope shows it to be a *muscovite-quartz slate* with a little biotite and chlorite. Part of the outcrop is a *muscovite schist* with quartz and calcite and spangled with biotite scales lying across the schistosity, also with rhombic plates of chlorite and ilmenite up to 0.2 inch. Near quarry No. 26 (Pl. I) a 3-foot thick granitic dike crosses the schist. This proves to be a light-gray fine-textured porphyritic biotite granite differing from "Barre granite" mainly in texture. There are here and there within the granite area strips of schist which are parts of the original capping left by erosion. There are also blocks of schist within the granite (inclusions) which probably dropped into the rising semiliquid granite from the under side of the fractured capping. These are described more fully on pages 18–19.

The pegmatite and aplite dikes which traverse the granite belong to a later stage of the period of intrusion, but after the consolidation of the granite. The basic dikes described later (p. 56) and referred to by Finlay [a] belong to a still later date. He describes as camptonite a 5-foot thick dike which crosses the schist just south of Barre on the road to South Barre, and he illustrates its spheroidal weathering.

[a] Op. cit., pp. 49, 50, Pl. VI.

"BARRE GRANITE."

"Barre granite" is known commercially as "dark Barre," "medium Barre," and "light Barre," with some exceptional "very dark Barre" and "white Barre." It appears to be everywhere a biotite granite in which the orthoclase is considerably kaolinized and micacized, but the microcline is fresh. The dark stone of the Milne & Wylie quarry and of the Jones dark quarry shows such a contrast between its hammered and polished faces as to indicate that the amount of soda-lime feldspar in it is larger than it is in the other granites of Barre or in biotite granites generally, and the thin sections show considerable plagioclase altered like the orthoclase. But Whitman Cross, of the United States Geological Survey, found a specimen of "dark Barre" quarried by Wells, Lamson & Co. to be a typical biotite-muscovite granite in which the amount of plagioclase (soda-lime feldspar) was so small as to place it among the accessory constituents. (See p. 76.[a])

The various shade designations of this granite are due in part to the different degree of kaolinization and micacization of its orthoclase feldspar, causing it to range from a translucent bluish gray to milk-white, and in part also to the varying content of black mica. Technically its shades are here defined as: (1) *Very light gray* (Wheaton quarry), equivalent to that of North Jay, Me.; (2) *light inclining to medium, slightly bluish gray* (Jones light quarry), between that of North Jay and of Hallowell, Me.; (3) *light medium bluish gray* (Smith upper quarry), between that of Hallowell, Me., and Concord, N. H.; (4) *medium bluish gray* (Duffee quarry), a trifle darker than "Concord granite;" (5) *dark inclining to medium bluish gray* (Bruce quarry); (6) *dark bluish gray* (Marr & Gordon quarry); (7) *very dark bluish gray* (Marr & Gordon quarry knots), equivalent to "dark Quincy." The chief product consists of (3), (4), and (5). The dark shades occur near the Williamstown line, the light near the top of Millstone Hill on its south and southwest sides, and also about three-fifths of a mile south-southwest of the top. The cause of this distribution is not evident.

Its texture ranges from fine to medium; that is, with feldspars up to 0.2 and 0.4 inch, generally, however, not exceeding 0.2 inch, few reaching 0.3 inch, so that it may be generally designated fine inclining to medium or medium inclining to fine. But the light granites of the Bond & Whitcomb quarry on Millstone Hill and of the Wheaton quarry on Cobble Hill are of medium texture with feldspars to 0.4 inch. Its mica particles range up to 0.1 and 0.2 inch, but in the "very dark" to 0.3 inch.

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[a] See Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1898, p. 224.

A. NODULAR GRANITE, ELLIS QUARRY, BETHEL.

The nodules are mainly muscovite, generally corrugated, and lie with their major axes in the plane of flow structure.

B. MICA SCHIST WITH GRANITE INJECTIONS.

Specimen at left (6 by 5 inches) from under side of large inclusion at Boutwell quarry, Barre, shows light granite bands alternating with dark bands of schist parallel to its foliation. Specimen at right (8½ by 3 inches) from edge of inclusion at Morrison quarry, South Ryegate. The light granite forms lenses in the schist foliation.

Its constituents, in descending order of abundance, are: (a) Clear colorless or bluish to translucent, and milk-white potash feldspar (orthoclase, kaolinized, and micacized, and less of clear microcline, rarely intergrown with a little soda-lime feldspar); (b) light smoky quartz, showing optical effects of strain, rarely with rutile needles, generally with fluidal and other cavities in sheets, and with rift cracks parallel to or coinciding with them, and in some sections with another set, of fewer and shorter sheets of such cavities, at right angles to the other and with grain cracks parallel to them (in one place the rift cracks extend into the feldspar and are there filled with fibrous muscovite);[a] (c) translucent to milk-white soda-lime feldspar (oligoclase-albite to oligoclase and oligoclase-andesine), some of it with flexed twining lamellæ, more or less kaolinized and micacized, and in places with calcite; (d) biotite (black mica), some of it chloritized; (e) a little muscovite or bleached biotite. The accessory minerals are pyrite, magnetite, titanite, allanite, apatite, zircon, rutile. The secondary are calcite, abundant within the orthoclase, one or two white micas, epidote, and chlorite. Minute veinlets of quartz, of calcite, and of epidote occur exceptionally.

An estimate of the mineral percentages made by the Rosiwal method on a piece of "dark" yielded these results:

Estimated mineral percentages in "dark Barre" granite.

Feldspar	65.522
Quartz	26.578
Mica	7.900
	100.000

All the "Barre granites" effervesce with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that the "light Barre" contains 0.49 per cent of CaO (lime), soluble in warm dilute (10 per cent) acetic acid, and the dark 0.63 per cent, indicating a content of 0.87 and 1.12 per cent of $CaCO_3$ (lime carbonate, calcite), respectively, the presence of which mineral is also shown by the microscope.

Finlay's analysis of the darker granite from the area south of Millstone Hill is given here for reference.[b]

Analysis of "dark Barre" granite.

SiO_2 (silica)	69.89
Al_2O_3 (alumina)	15.08
Fe_2O_3 (iron sesquioxide)	1.04
FeO (iron oxide)	1.46
MgO (magnesia)	.66

[a] Finlay (op. cit., p. 54) describes these rift cracks as crossing from one quartz crystal particle to another without interruption, and as containing arborescent crystalline growths, possibly of manganese dioxide.
[b] Op. cit., pp. 55, 56.

CaO (lime)	2.07
Na_2O (soda)	4.73
K_2O (potash)	4.29
H_2O at 110° (water uncombined)	.31
H_2O ignition (water combined)	.23
P_2O_5 (phosphorus pentoxide)	Trace.
	99.76

W. C. Day found the specific gravity of "dark Barre" and "medium Barre" to be 2.662 to 2.672, and its crushing strength to range from 14,968 to 19,957 pounds per square inch. (See p. 77.) L. P. Kinnicutt in 1908 found that 100 pounds of "Barre granite" absorb 0.294 pound of water. (See p. 112.)

"Barre granite" is mostly monumental, but some is building granite. The light, medium, and dark monumental stone, although brilliant in the rough, has weak mineral contrasts, but these are stronger on the polished face of the dark. The white of the more kaolinized and micacized orthoclase feldspars and the black of the mica, and the combined bluish gray of some of the feldspar and smoke color of the quartz form three distinct shades, but owing to the fineness of the texture these merge a few feet away, and the white alone shows against a dark-gray ground. "Light Barre" granite is never polished, but is hammered, because of the feeble contrast between the polished and cut surface, but the dark is often used for polished work. Its polish is fair, and the contrast between the polished and cut face is more marked along the hard way than in the rift or grain directions. In the Milne & Wylie and Jones dark quarry stone this contrast is so marked as to imply the presence of considerable soda-lime feldspar, for the contrast is almost as great as in a quartz monzonite. The polished face shows pyrite and a little magnetite.

GEOLOGY OF BARRE QUARRIES.

The granite was observed in contact with the schist at seven quarries (Pl. I, Nos. 6, 8, 9, 10, 12, 20). The results of a study of the contact phenomena at two of these are given on pages 21–23.

The schist inclusions have already been dwelt upon (pp. 18, 19). At two quarries (Pl. I, Nos. 6, 32) these inclusions have been penetrated by minute dikes of granite and pegmatite proceeding from the granite, as has been the schist capping. At one of these quarries the granite is darkened for a space of 7 feet from the inclusion.

The sheet structure of Millstone Hill appears to form a more or less unsymmetrical flattish dome. The central part of this is exposed at the Wetmore and Morse quarry (Pl. I, No. 14), where the sheets dip from the horizontal both eastward and westward 10°. West-southwest of that point and lower down, at the Smith upper quarry (Pl. I, No. 15), they dip 10° to 15° SW., and so also in the Duffee

quarry; still farther down, at the Smith lower quarry (Pl. I, No. 17), they dip 20° to 30° SW. On the northeast side, at the Bond & Whitcomb quarry (Pl. I, No. 19), the sheets dip low to the northeast, and at the next quarry (Pl. I, No. 26) 15° E.; at the Canton quarry (No. 21) 10° N., but at the Barney quarry (No. 20) 10° NE. and NW. At the Walker quarry (No. 23) low east and northeast. An east-northeast to west-northwest section of the hill passing through the quarries named would thus give a general low anticlinal structure. The sheets of Cobble Hill also form a dome, for at the Wheaton quarry, north-northwest of the top, they dip 10° NW. and NNE., but on the southwest side of the hill, at the Wildbur quarry, they dip 60° S. 75° W., and at the Bianchi quarry, farther south, 35° S. 50° W. But the sheet structure half a mile southeast of Millstone Hill (Jones and Consolidated quarries) and toward the Williamstown line is too complex to unravel. The sheets are lenticular and normal at only 21 out of the 41 quarries visited. These 21 quarries include, besides those named above, the small group of quarries in the northwest corner of the map (Pl. I), also the Milne & Wylie, the Anderson, Acme, O'Herin, Wells-Lamson, and Pruneau quarries, also the Pirie, in Williamstown. In the remaining 20 quarries the sheets are more or less irregular or absent. In places the lenses are very short and thick, in others, as in the large Jones Bros. quarry, there are only traces of sheets. In several quarries, as the Manufacturers and Anderson quarries, the sheets "grow on"—that is, the sheet partings stop laterally, leaving the center or half of the quarry without sheets. Figure 16 shows close joints without sheets in one part of the quarry, and sheets without joints in the adjoining part. In several quarries sheet structure stops vertically at depths of 20, 25, or 35 feet from the rock surface; for example, at the Barclay, Capital, and Milne quarries. At the Smith lower quarry there is a mass 58 feet thick without sheets; at the Bruce, one such of 48 feet; at another of 40 feet, and at the Marr & Gordon of 80 feet. At some quarries there is no trace of sheet structure. This incomplete development of sheet structure is the chief difficulty in quarrying at Barre. Wherever low dipping joints occur these are utilized as sheets, but where such are wanting horizontal channeling has to be resorted to, which is expensive. The sheets range from 6 inches to 30 feet in thickness. At the Wells-Lamson quarry the "toe-nail" structure intersects the sheets. At one quarry a sheet surface is slickensided.

There are ten sets of joints: (a), striking N. 5° W. to 10° E.; (b) N. 15° to 20° E.; (c) N. 30° to 40° E.; (d) N. 45° to 55° E.; (e) N. 60° to 70° E.; (f) N. 75° to 90° E.; (g) N. 60° to 80° W.; (h) N. 45° to 50° W.; (i) N. 30° to 40° W.; (j) N. 10° to 25° W. Of these (c) occurs at 21 and (f) at 18 quarries. The next most frequent are (e) and (i), each at 10 quarries, and (j) at 8. These joints divide

themselves into five complementary sets; that is, sets at right angles to one another and presumably due to the same strain. These sets consist of (a) and (f), (b) and (g), (c) and (h), (d) and (i), and (e) and (j). The spacing of the joints ranges from 1 to 200 feet. In 26 quarries the spacing ranges from a minimum of 1 to 8 feet to a maximum of 20 to 50 feet; in 18 quarries from a minimum of 10 to a maximum of 100 to 200 feet. Many of the joints are intermittent or discontinuous. Abnormal relations of joints and sheets are shown in figure 16. In some quarries joints of the same strike incline in opposite directions, as shown in figure 14.

Some joints are coated with limonite and calcite; others with a greenish, usually slickensided film of muscovite, secondary quartz, and chlorite. Back of it the feldspars are microscopically brecciated and cemented with fibrous muscovite, also minutely veined with calcite and quartz. These veins run at right angles to the face. Some joint faces are very uneven and their minor protuberances slickensided. Other joint faces are coated with somewhat large muscovite scales. The slickensides of joints usually have their furrows pointing in the direction of the dip of the joint, indicating motion up or down along the dip.

Headings are numerous and usually rusty. On the northwest wall of the Marr & Gordon quarry the central part (25 feet) of a heading striking N. 35° E. branches off to the northwest; and at another quarry (p. 80) a heading undulates back and forth laterally.

Flow structure is rarely observable. At the Wells-Lamson quarry (Pl. I, No. 24) a 12-inch band of darker granite shows the flow to have been N. 70° E., with an inclination of 60° N. 20° W. On Cobble Hill (Bianchi quarry) it is about north and vertical. At the Barney quarry for a space of 15 feet from the contact with schist the granite is coarse and fine in alternating bands.

Segregations are uncommon. At the Sanguinetti quarry (Pl. I, No. 18) the granite is concentrically banded in a pear-shaped mass, 1 and 2 feet in its diameters. Biotitic knots are rare and small. One 1.5 by 0.5 inch was noted. Possibly the darker, more biotitic, irregular roundish portions of the granite near the schist contacts at the Marr & Gordon and Jones dark quarries (pp. 62, 86) are of the nature of segregations.

The rift as reported by foremen is everywhere vertical and the grain in all but two quarries is horizontal. The course of the rift about Millstone Hill and in Williamstown appears to range from N. 30°, 35°, 40°, 42°, 45°, 50°, 55° to 60° E. and on Cobble Hill from N. 50° to 75° E. In the group of quarries about the Boutwell and Bruce quarries and the adjoining ones in Williamstown the rift ranges from N. 50° to 60° E., but near the top of Millstone Hill (Duffee, Bond & Whitcomb) from N. 30° to 40° E. At the Capital and Barre quarries

(Pl. I, Nos. 29, 33) it is reported as varying in different blocks. At the Anderson quarry (Pl. I, No. 8) as N. 60° E., and the grain, here better than rift, as dipping 20° N.; but at the Jones light quarry, only 1,500 feet away, the rift is reported as N. 35° E. and the grain as horizontal. At the Pirie quarry the grain is reported as dipping 35° N. 30° W. The courses of rift and grain are thus far from uniform, and the cause of their variation is not apparent. It is to be noted, however, that the general course of the rift has a range like that of the strike of the schist foliation, which suggests the possibility of both being due to the same cause.

Pegmatite dikes are not abundant. The Pirie quarry is crossed by one 3 feet 6 inches wide, with a N. 65° E. course, consisting almost entirely of light bluish-gray feldspars, and with a 6-inch biotitic border on either side with biotite crystals pointing toward the center. This dike has small lateral branches up to a foot long. A 1-foot pegmatite dike intervenes between schist and granite at the Anderson quarry (see fig. 5) and the schist capping is injected with minute dikes of pegmatite up to 4 feet long. (See p. 22.) At the Barney quarry a pegmatite lens occurs between granite and schist. A muscovite and feldspar (1.75 inches thick) coating on a joint plane at the Pruneau quarry (p. 78) is probably of pegmatitic origin, and likewise one of quartz and muscovite at the Manufacturers' quarry (p. 82).

Aplite occurs in irregular veinlike masses in contact with schist inclusions at two quarries. Specimen D, XXIX, 14, a, from the Jones dark quarry, is of light medium bluish greenish gray and of very fine texture with mica up to 0.05 inch, its other minerals not distinguishable. In thin section this consists of microcline, kaolinized albite to oligoclase-albite, and quartz with a little biotite, some of it chloritized, and still less muscovite or bleached biotite. It contains allanite and carbonate. Specimen 44, c, from the Bailey quarry, is of light medium purplish gray and of porphyritic texture. It consists of light purplish gray to milk-white feldspar, clear quartz, and black mica. The particles of matrix are from 0.025 to 0.1 millimeter in diameter. The porphyritic crystals (mostly oligoclase-albite, some with zonally arranged quartz, rarely microcline) measure from 0.25 to 1 by 0.5 millimeter. Pyrite is accessory.

Quartz veins, from 0.05 to 2 inches wide, are more abundant. At the Milne quarry (Pl. I, No. 34) veins of smoky quartz with diagonal fractures recur at intervals of 3 feet with a N. 60° E. course.[a] The granite for 0.2 inch next to a vein is largely feldspar. Along the edge of the vein there are bands of fibrous muscovite and, in places, streaks of granulated quartz. Sheets of fluidal cavities run discontinuously parallel to the vein and at right angles to it, and cracks here and there with granular quartz zigzag along these directions. Similar

[a] Referred to in Bull. U. S. Geol. Survey No. 354, p. 44.

veins with pegmatite strike N. 40° E. Both are evidently of pegmatitic origin. At the Boutwell quarry (see p. 58 and fig. 13) the granite parts along minute veins of quartz and muscovite with N. 10° E. course. Another little vein or dike with N. 80° E. course and 0.05 inch wide consists of alternating sets of contiguous quartz and feldspar particles. The quartz particles have sheets of cavities and cracks, both parallel to the course of the vein. It has also a border, 0.25 inch wide, on either side of bleached biotite or muscovite, with chlorite, fibrous muscovite, and feldspar veined with calcite, together with magnetite particles of some size staining the rock with limonite. Quartz veins also occur at the Canton and Pruneau quarries.

Basic dikes were noted at seven quarries. At three (Jones light, Capital, and McIver & Matheson) the exposures may all belong to one dike, which would thus be one-half mile long; and as two others (Barney and Walker quarries) are clearly the same dike, thus 800 feet long, only four dikes were actually observed. The long one is from 2 feet 6 inches to 9 feet thick with a N. 40° to 45° E. course and vertical. The other, from 1 to 2 feet thick, has a N. 35° to 40° E. course. One at the Bond & Whitcomb quarry, up to 2 feet thick, has a N. 25° W. course and weathers spheroidally. One at the Bianchi quarry on Cobble Hill is 6 inches thick with a N. 55° E. course. Two of these dikes were examined in thin section: The Jones light quarry dike rock is a dark greenish diabase of very fine texture (labradorite, augite, magnetite, apatite needles, secondary calcite). Its augite is altered to a chlorite-like mineral giving the greenish color. The Bond & Whitcomb dike rock appears to be an altered camptonite of very dark gray shade and porphyritic texture with very fine matrix (plagioclase, micacized, kaolinized, and with calcite, magnetite in crystals, and skeleton crystals). The porphyritic crystals or masses appear to be hornblende more or less altered to chlorite and calcite; one is replaced by quartz.

At three quarries the granite within 1 to 2 feet of these dikes is crossed by vertical subjoints 1 to 6 inches apart parallel to the dike wall; and the granite scales off along them. These subjoints are to be regarded as the effect either of the heat of the dike or of the strain which accompanied its intrusion.

A north-south compressive strain is reported at the Bruce and Wells-Lamson quarries, and an east-west one at the Canton quarry. (See fig. 2.)

The formation of granite sand by decomposition between sheet surfaces was noted at the Innes & Cruikshank quarry.

Rusty stain ("sap") along sheet surfaces varies greatly in amount. In many quarries it does not exceed 6 inches in thickness; in others it reaches 12, 16, and 18, and in one place 24 inches, but that was confined to the upper sheets. Generally it is confined to the lower

surfaces of sheets. On joint faces it is from 6 to 24 inches, and abounds on headings.

In concluding this part of the subject attention is recalled to the evidence of minor mineral and structural changes brought out in this and the previous section. The rift and grain cracks in the quartz, the straining of the quartz as shown by its optical behavior, the bending of the twinning lamellæ of the soda-lime feldspars, the formation of minute veins of secondary quartz, calcite, and epidote, the brecciation of feldspars and the formation of fibrous muscovite and of chlorite and of little veins of quartz and calcite in consequence of motion along joint planes, the formation of subjoints near basic dikes—all these facts point to crustal movements of different dates, some probably preceding the sheet and joint structure, others subsequent to it.

BOUTWELL QUARRY.

The Boutwell quarry is about south of the top of Millstone Hill, in Barre. (See Pl. I, No. 1.) Operator, Boutwell, Milne & Varnum Company, Barre, Vt.

The granite, chiefly "dark Barre" (but also some "dark medium" and "medium"), is a biotite granite of dark, inclining to medium, bluish-gray shade and of fine, even-grained texture, with feldspars up to 0.2 inch and mica to 0.1 inch. Its shade, texture, constituents, and qualities correspond to those of the "dark" of the Bruce quarry described on page 58.

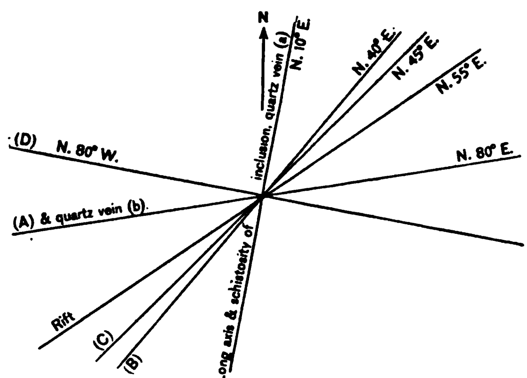

FIGURE 13.—Structure at Boutwell quarry, Barre.

The quarry, opened about 1886, is somewhat T-shaped, measuring about 600 feet in a N. 80° E. direction by 60 feet north-south at the east end and 120 feet at the west end, with a 150-foot square extension on the north side, but only 150 feet from the west end. Its depth is from 50 to 100 feet.

The sheets are irregular, 4 to 30 feet thick, striking N. 30° E. and also east-west, and dipping 10°, 20°, and 35° N. 30° W. and north. Joint, rift, and dike courses are given in figure 13.

Joints (A) dip 55° to 70° S. 10° W., are spaced 5 to 50 feet, and form the north and south walls of the main part. They are mostly limonitic or slickensided with a lustrous greenish coating, described on page 54. (B) is vertical, discontinuous, only a few feet long, forms small headings, and is coated with calcite and limonite to

0.25 inch. One at the southeast corner dips 60° N. 40° W. (C) dips 10° S., exceptional, only a few feet long, with lustrous coating, as under (A). The rift is reported as vertical and grain as horizontal. Three large schist inclusions measure respectively 55 by 10 by over 6 feet; 20 by 4 by 3 feet; and 10 by 8 feet. The first has been described on page 19. A minute vein (a) of muscovite and quartz dips 50° E. The granite parts along it. Vein (b) is scarcely 0.05 inch wide, but has a border of dark bluish green (chloritic) or brown (limonitic), 0.25 inch wide on either side. (See further p. 56.) The "sap" is from 8 to 12 inches thick on the lower surfaces of sheets and is conspicuous in the headings.

The plant of this and the four other quarries operated by this company includes a 75-ton wooden derrick, one of 50, three of 40, four of 30 to 35, one of 25, two of 20, two of 10, and one of 5 tons; two hoisting engines (capacity, 15 tons on straight rope, and 25 tons with multiplied power); two Blondin carriers (capacity 15 and 5 tons) and engines; an air compressor (compound Corliss, 640 cubic feet of air per minute); 33 steam rock drills; 57 air plug drills; 18 steam pumps; and a stone crusher.

Transportation is effected by siding and connections with the Central Vermont and the Montpelier and Wells River railroads.

The product is all for monumental use, and its market is general. A specimen of the product from all the quarries of this firm is the Joseph Smith memorial at South Royalton, Vt.

BRUCE QUARRY.

The Bruce quarry adjoins the Boutwell on the southwest and lies about south of the top of Millstone Hill, in Barre. (See Pl. I, No. 2). Operators, A. E. Bruce & Sons, Barre, Vt.

The granite (specimen D, XXIX, 12, a), "dark Barre," is a biotite granite of dark inclining to medium bluish-gray shade, and of even-grained fine texture, with feldspar up to 0.2 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are translucent bluish-gray to milk-white potash feldspar (orthoclase, kaolinized and micacized, and a little clear microcline, one such orthoclase inclosing a fresh microcline); light smoky quartz, with cavities in sheets and with cracks parallel to them (the quartz shows optical effects of strain); milk-white soda-lime feldspar (oligoclase-albite), more or less altered, rarely with bent twinning planes; biotite (black mica); and a little muscovite or bleached biotite. Accessory: Titanite, magnetite, pyrite. Secondary: Not a little calcite within the orthoclase, kaolin, one or two white micas. The stone effervesces slightly with cold dilute muriatic acid.

Its mineral contrasts are feeble owing to fineness of texture and the lightness of quartz. There is some contrast between the polished and cut face along the hard way.

The quarry, opened in 1890, is about 250 feet in a N. 80° E. direction by 125 feet north-south and from 60 to 100 feet in depth.

The sheets are from 4 to 10 feet thick, and dip 5°-10° N. At the bottom is a mass 48 feet thick without sheets. There are three sets of joints: (a), striking N. 80° E., with varying dip, forms the south wall and an 8-foot heading on the north wall, spacing 10-20 feet, but makes wedge-shaped masses owing to varying dip; (b), diagonal, "slide," strikes N. 40° E., vertical, at northwest corner, with uneven slickensided face; (c), striking N. 20° W., dipping 70° N. 70° E., one in center. The rift and grain are as at Boutwell quarry. A heavy north-south compressive strain is reported.

The plant comprises three derricks (50 and 15 tons), one steam and one electric engine, three large rock drills, nine air plugs drills, and two steam pumps. Compressed air is obtained from the plant of Jones Brothers.

Transportation is by siding, as shown on the map (Pl. I).

The product is used for monuments, and its market is general. Examples are the Calhoun Monument, Lexington, Ky., and 18 regimental monuments in the national cemetery at Chattanooga, Tenn.

MILNE & WYLIE QUARRY.

The Milne & Wylie quarry adjoins the Bruce quarry on the south, and lies about south of the top of Millstone Hill, in Barre. (See Pl. I, No. 3.) Operator, Boutwell, Milne & Varnum Company, Barre, Vt.

The granite (specimens D, XXIX, 11, a, b, c), "dark Barre," is a biotite granite of dark bluish-gray shade, a trifle darker than that of the Bruce quarry, and of even-grained fine inclining to medium texture with feldspars up to 0.3 inch and mica to 0.12 inch. Its constituents are the same as those of the Bruce and Marr & Gordon quarry stone described on pages 58, 61, but it contains considerable soda-lime feldspar, more or less kaolinized and micacized and with calcite. Its strong contrasts of shade between cut and polished faces also indicate the presence of an unusual amount of soda-lime feldspar, for a biotite granite. It effervesces with cold dilute muriatic acid.

An estimate of the mineral percentages by the Rosiwal method yields the following results with a mesh of 0.2 inch and a total linear length of 66.6 inches:

Estimate of mineral percentages in Milne & Wylie "dark Barre" granite.

Feldspar	65.522
Quartz	26.578
Mica	7.900
	100.000

The average size of all the particles obtained from the same measurements, adding 50 per cent to the number of feldspar particles for the unseparated second feldspar, proves to be 0.069 inch, that of the feldspar 0.074, the quartz 0.079, and the mica 0.033 inch.

The polished face shows a little pyrite and less magnetite. The cut or hammered hard-way face is as light as the cut face of the Jones "light Barre," thus affording a very marked contrast with the polished face. The mineral contrasts in the rough are weak, but stronger on the polished face, white, black, bluish gray, and smoke color being easily distinguished in it within a distance of 2 feet. The polish is fair.

The quarry, opened about 1887, is about 400 feet east-west by 200 feet across, but with a mass 100 by 50 feet projecting into the quarry from the east wall.

The sheets, from 3 to 30 feet thick, dip 20° to 30° NW. Joints, one set only, strike nearly east-west, dip 60° to 70° S., form the north and south walls and a heading which constitutes the projecting mass on the east wall. These joints, being spaced 3 to 20 feet, cut up the sheets.

The plant is included in that of the Boutwell quarry, and the transportation and product likewise.

EMPIRE QUARRY.

The Empire quarry is southwest of the Milne & Wylie quarry and about south-southwest of the top of Millstone Hill, in Barre, just north of the Williamstown line. (See Pl. I, No. 4.) Operator, Boutwell, Milne & Varnum Company, Barre, Vt.

The granite is like that described from the Bruce quarry (p. 58).

The quarry, opened about 1888, is about 375 feet in a N. 75° E. direction by 200 feet across and from 75 to 120 feet in depth.

The sheets, from 3 to 18 feet thick, are somewhat irregular, dipping low, rarely 40° to 45° N. There are two sets of joints: (a), striking N. 65° to 70° E., dipping 65° to 70° S. 15° E., is spaced 4 to 25 feet, forms a heading on the north wall, a 10-foot one on the south wall, and a 25-foot one in the middle. This set exceptionally dips 65° to 70° N. 15° W., forming with the rest a V-shaped heading in the center of the quarry, as shown in figure 14. The faces of (a) are coated with limonite and bordered with its stain. The other set (b) is exceptional, striking N. 15° W., vertical. The rift and

grain are as at adjoining quarries. There are three schist inclusions on the east wall, the largest 20 by 10 feet.

The plant, transportation, and product are covered by those items under the Boutwell quarry.

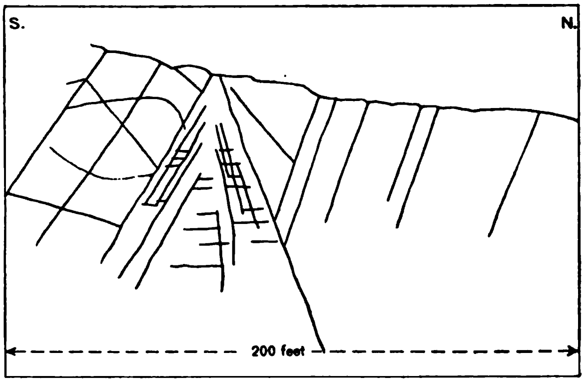

FIGURE 14.—Structure on west wall of Empire quarry, Barre.

MARR & GORDON QUARRY.

The Marr & Gordon quarry is east-southeast of the Empire quarry and about south-southwest of the top of Millstone Hill, in Barre, just north of the Williamstown line. (See Pl. I, No. 5.) Operator, Boutwell, Milne & Varnum Company, Barre, Vt.

The granite (specimens D, XXIX, 8, b, bb, d), "dark Barre" (derrick 9), is a biotite granite of dark bluish-gray shade and of even-grained fine texture with feldspars up to 0.2 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Bluish clear to translucent and milk-white potash feldspar (orthoclase, kaolinized and micacized, with a little clear microcline), some of it with minutely intergrown soda-lime feldspar; light smoky quartz with cavities in sheets and showing marked optical effects of strain; translucent to milk-white soda-lime feldspar (oligoclase to oligoclase-andesine) rarely with curved twinning lamellæ, more or less altered; biotite (black mica), rarely chloritized; very little muscovite or bleached biotite. Accessory: Pyrite, magnetite, zircon, titanite, apatite. Secondary: Calcite (in orthoclase), kaolin, one or two white micas, and chlorite.

The stone effervesces with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.63 per cent of CaO (lime) soluble in warm dilute (10 per cent) acetic acid, which indicates a content of 1.12 per cent of CaCO (lime carbonate, calcite), the presence of which mineral is also shown by the microscope.

This granite is regarded by the firm as harder and darker than the "dark" from its other quarries. It resembles that of the Milne & Wylie quarry (p. 59), but when polished shows somewhat higher mineral contrasts. It takes a fair polish. The polished face shows some pyrite and magnetite.

At the west end of the quarry, near the contact of granite and schist, is a mass (so-called knot) of still darker granite of sufficient size for commercial use. This "very dark Barre" (Specimen D, XXIX, 8, a) is a biotite granite of very dark bluish gray shade, much darker than the "dark" and as dark as "dark Quincy"[a] and of fine inclining to medium, even-grained texture, with feldspars up to 0.2 inch and mica to 0.3 inch. Its constituents are the same as those of "dark Barre," specimen 8, b, etc., but the biotite is much more abundant. The second feldspar is oligoclase-albite. The stone effervesces with cold dilute muriatic acid.

In the main opening the sheets are unusually irregular. At the east end they are 18 to 20 feet thick, but in the northwest part for a depth of 80 feet there are none. In the small opening the sheets are more regular and from 4 to 14 feet thick. There is but one set of joints, striking N. 35° E. and vertical, forming a 20 to 25-foot heading on the northwest wall, also the northwest wall of the smaller opening, where it recurs at intervals of 3 to 10 feet. The heading in the main quarry branches off diagonally to the northwest, forming a band 20 to 30 feet wide, about halfway down the quarry. This unusual structure indicates complex strains. At the top of the west end the granite is in contact with a quartz-biotite schist spangled with biotite scales. The two rocks are firmly welded together in places across the foliation of the schist. Near this schist the granite is much darker from more abundant and larger biotite scales. (See p. 21.) The outline of the darker stone is quite irregular. The rift is reported as vertical, with N. 55° E. course, and the grain as horizontal.

The plant of these openings has been included in that of the Boutwell quarry, page 58.

Transportation is by sidings, as shown on the map (Pl. I).

BAILEY QUARRY.

The Bailey quarry is southeast of the Milne & Wylie quarry and about south of the top of Millstone Hill, in Barre. (See Pl. I, No. 6.) Operators, Woodbury & Bailey, Graniteville, Vt.

The granite, "dark Barre," is a biotite granite of dark shade and fine even-grained texture, similar to that of the Bruce and the Milne & Wylie quarries.

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[a] See Bull. U S. Geol. Survey No. 354, p. 98.

The quarry is about 135 by 75 feet and from 10 to 35 feet in depth.

The sheets are imperfectly developed. There are two sets of joints: (a), striking N. 20° W., dipping 70° N. 70° E., is spaced 3 to 20 feet; (b), striking N. 60° E., dipping 75° S. 30° E., spaced 2 to 6 feet, occurs on the west side only. There the granite is in contact with schist which has a foliation strike of N. 60° E., dip of 35° N. 30° W., also one of N. 20° E., with vertical dip. At the northwest corner is a schist inclusion 26 by 5 feet, with a foliation striking N. 85° W. and a dip of 55° N. Dikes, large and minute, of pegmatite and aplite penetrate the schist capping and the inclusion, rendering the relations intricate. Some of the details are given on page 23.

The plant comprises a derrick and hoisting engine, an air compressor (capacity 150 cubic feet of air per minute) driven by a 30-horsepower electric engine, a large steam rock drill, six air plug drills, and a steam pump.

Transportation is by cart, over 4 miles to Barre.

The product is used for monuments.

BARRE GRANITE COMPANY'S QUARRY.

The Barre Granite Company's quarry consists of two openings adjoining the Bruce and the Milne & Wylie quarries, in Barre. (See Pl. I, No. 7.) Operator, Barre Granite Company, Barre, Vt.

The granite, "dark blue," is a biotite granite of dark and dark inclining to medium bluish-gray shade and of even-grained fine or fine inclined to medium texture identical with the "dark Barre" of the Bruce and the Milne & Wylie quarries described on pages 58, 59.

The quarries, opened about 1884, are roughly estimated as measuring about 150 by 125 feet and 60 feet square, respectively, and as about 45 feet deep.

The sheets are irregular. The jointing is like that of the adjoining quarries.

The plant comprises two derricks, a double (four-drum) hoisting engine, and a steam pump.

These quarries have not been operated since 1904, owing, it is reported, to disagreement among the partners as to necessary improvements.

ANDERSON QUARRY.

The Anderson quarry is about S. 10° E. of the top of Millstone Hill, in Barre, 1,800 feet northeast of the Williamstown line. (See Pl. I, No. 8.) Operator, Granite City Quarry Company, Barre, Vt.

The granite, reported by the superintendent as "dark Barre," but entered in the legend of the original quarry map of Walker

& Gallison as "medium," is a biotite granite of gray shade and fine even-grained texture.

The quarry, opened about 1892, measures about 200 feet in a N. 45° W. direction by 150 feet across and from 50 to 75 feet deep.

The granite on the southeast and northeast sides and on the southwest side for 50 feet west of the south corner is capped by schist and slate up to 15 feet thick, with a cleavage and schistosity striking N. 30° E. and dipping 55° N. 40° W. The relations of granite and slate are shown in figures 5 and 6, and the contact phenomena have been given on page 21. The sheets, from 1 to 15 feet thick, dip 20° NW. There are three sets of joints: (a), striking N. 50° W., dipping 75° N. 50° E., occurs on the southwest side only; (b), striking N. 5° E. and dipping 70° E., is spaced 6 to 15 feet; (c), striking N. 60° E. and dipping 75°, is spaced 3, 15, and over 25 feet. The rift is reported as vertical, with N. 60° E. course; the grain as dipping with the sheets 20° NW., and as easier than the rift. A 1-foot pegmatite dike borders one of the schist masses, as shown in figure 5. At the east side there are two schist inclusions, measuring 10 by 2 to 3 feet and 6 by 2 feet, respectively, besides minor fragments.

The plant consists of a derrick, a Blondin carrier, two engines, an air compressor (capacity about 200 cubic feet of air per minute) driven by the Blondin engine, two large rock drills, four air plug drills, and a steam pump.

Transportation is by cart, over 4 miles to Barre.

The product is used entirely for monuments.

STEPHEN & GERRARD QUARRY.

The Stephen & Gerrard quarry is 600 feet north of the Anderson quarry and from south to south-southeast of the top of Millstone Hill, in Barre. (See Pl. I, No. 9.) Operators, Stephen & Gerrard, Barre, Vt.

The granite, reported by the firm as "medium Barre," but entered on Walker & Gallison's original map as "light," is a biotite granite of gray shade and of even-grained fine texture. For descriptions of "medium Barre" and "light Barre," see pages 65, 71. The quarry measures about 175 feet in a N. 30° E. direction by 150 feet across and from 20 to 50 feet in depth.

The sheets are undeveloped in the west half of the quarry, but the closely spaced joints there serve the quarrymen instead. Rift and joint courses are shown in figure 15 and the complex relations on the north wall in figure 16. There are four sets of joints: (A) dips 35° S. 40° E., and is spaced 3 to 17 feet; (B), vertical, is spaced 30, 40 to 90 feet and forms the south wall; (C), diagonal, dips 35° E., one only in east half; (D), vertical, forms heading on south wall. The granite is

in contact on the west side and southeast corner with schist which has a foliation striking N. 30° E. and dipping 50° N. 60° W. Rusty stain is from 1 to 6 inches thick on sheet and joint faces.

The plant consists of two derricks (one of 40 tons), two hoisting engines, a small air compressor, two large rock drills, five air plug drills, and a steam pump.

Transportation is by cart, 4½ miles to cutting sheds.

The product is used entirely for monuments.

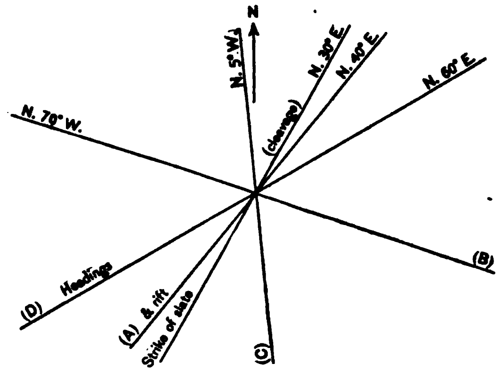

FIGURE 15.—General structure at Stephen & Gerrard quarry, Barre, Vt.

JONES LIGHT QUARRY.

The Jones Light quarry is about northeast of the last and south-southeast of the top of Millstone Hill, in Barre. (See Pl. I, Nos. 10 and 11.) Operator, Jones Brothers Company, Barre, Vt.

The granite (specimen D, XXIX, 27, b), "light Barre," is a biotite granite of light, very slightly bluish gray shade. Its position among the light granites is between that of North Jay, Me., which is very light gray, and that of Hallowell, Me., which is light, inclining to medium.[a] Its texture is even grained, fine inclining to medium, with feldspar up to 0.2 inch, rarely 0.3 inch, and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Clear, colorless to bluish translucent and milk-white potash feldspar (orthoclase, kaolinized and micacized, with fresh microcline); very light smoky quartz with sheets of cavities with brightly polarizing rift or grain cracks parallel to or coinciding with them; translucent to milk-white soda-lime feldspar (oligoclase-albite, more or less altered), rarely with bent twinning planes; biotite (black mica), some of it chloritized; very little muscovite or bleached biotite. Accessory: Magnetite (very little) and zircon. Secondary: Calcite, usually in the orthoclase, kaolin, one or two white micas, and chlorite.

The stone effervesces with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.49 per cent of CaO (lime) soluble in warm dilute (10 per cent)

[a] See Bull. U. S. Geol. Surv. No. 313, 1907, pp. 80, 117.

acetic acid, which indicates a content of 0.87 per cent of $CaCO_3$ (lime carbonate, calcite), the presence of which is also shown in thin section.

The mineral contrasts are feeble and so are those between cut and polished faces. The stone is used for rough, hammered, and carved monumental work.

The quarry consists of two openings. The main and older one measures over 550 feet in a N. 35° E. direction by 60 to 200 feet across, and 40 to 90 feet in depth. The new one, which lies 300 feet N. 30° E. from the north end of the other, is about 200 feet square and 50 feet deep.

Joint, rift, and dike courses are shown in figure 17. Sheet structure is hardly developed or very irregular. Traces of sheets dip 10° W. On account of this much horizontal channeling has to be done. There are six sets of joints: (A), diagonal and vertical; (B), also vertical, spaced 20 to 30, 50 feet and over; (C) dips 45° S. 45° E., discontinuous, occurs here and there in north part of quarry; (D) dips 45° W.,

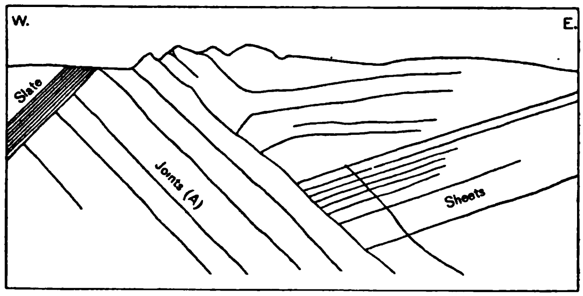

FIGURE 16.—Structure on north wall of Stephen & Gerrard quarry, Barre, Vt.

undulating, occurs with (C); (E), in new opening, dips 45° N. 65° E., spaced 3 to 50 feet, forms a heading at northwest corner; (F), in new opening, dips steeply N. 58° E., several at north end. There is a schist capping on the west wall of the main opening 10 to 20 feet and more thick, and on part of east wall, and also forming the east wall of new opening. Its foliation strikes N. 35° E. and dips steeply west to 90°. The schist is said to continue indefinitely on the east and also to be at least 150 feet wide on the west. Rift is vertical and good, the grain horizontal. A vertical diabase dike, 8 feet thick, crosses the north half of the main quarry diagonally, and also the schist capping. (See, further, p. 56.) Thirty feet below the granite surface is a schist inclusion 30 feet long and up to 3 feet thick, tapering.

The plant, for both openings, includes two 65-ton derricks, two 40-ton ones, and two smaller; a 125-horsepower hoisting engine, one of 50, and two of 40; an air compressor (capacity 750 cubic feet of air per minute; 11 large rock drills, 20 air plug drills, and two steam pumps.

The cutting plant, which is in Barre, includes an outside 100-ton derrick, two pneumatic 3-ton hoists, three overhead 20-ton cranes, an air compressor (capacity 1,200 cubic feet of air per minute), six air plug drills, 180 air hand tools, seven surfacers, seven polishers, two cutting lathes for stones 25 by 3 feet, a polishing lathe for stones of the same size, two gangs of stone saws for stones 12 by 7 feet, two MacDonald rotary surfacers, an automatic polishing carriage with bed 18 by 4 feet, a Cavecchi polishing machine, and three granite-boring machines. Power is supplied by a 150-horsepower Corliss engine and also by Stephen Brook.

Transportation is effected by sidings from the quarry and the cutting plant, which are several miles apart.

The product is used for rough and hammered face and carved monuments. The following specimen monuments combine the product of this quarry with that of the firm's dark quarry described on page 85: Ohio and Iowa state soldiers' monuments, Chattanooga, Tenn.; Governor Curtin monument, Bellefonte, Pa.; state soldiers' monument, York, Pa.; Hearn monument, with monolithic spire 53 by 4 by 4 feet, Woodlawn, N. Y.; Rouse mausoleum, Winchester, Va.; Krueger mausoleum, Newark, N. J.; Gary mausoleum, with roof stones of the "light," 35 by 9 feet 6 inches by 1 foot 6 inches each, Wheaton, Ill.

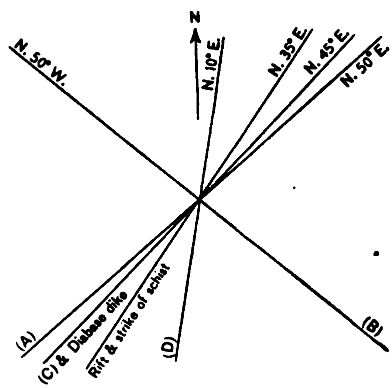

FIGURE 17.—Structure at Jones Light, main quarry, Barre.

BARCLAY QUARRY.

The Barclay quarry is the S. 35° W. continuation of the large Jones Light quarry, as shown on Plate I, No. 12. Operators, Barclay Brothers, Barre, Vt.

The granite, "light Barre," is a biotite granite of light, slightly bluish gray shade and even-grained fine inclining to medium texture, identical in every respect with that of the Jones Light quarry described on page 65, but the lower part of the quarry is said to have yielded "medium Barre" granite.

The quarry, 220 by 100 feet, is about 75 feet deep. The firm owns also another quarry in line with this, the "Sunnyside," which, however, was idle in 1907.

The sheets from 6 inches to 12 feet and over in thickness dip 20° NW., but sheet structure terminates at a depth of 35 feet. Joints and rift are the same as in the Jones Light quarry. The granite is

capped by schist on the northwest side. The schist is spangled with minute crystals of biotite and with a few garnets.

The plant at the quarry comprises a 30-ton and a 40-ton derrick, two hoisting engines, an air compressor, two large rock drills, three smaller ones, four air plug drills, and a steam pump. At the cutting shed in Barre it comprises a hand derrick, two overhead 40-ton cranes, three air compressors (capacity, two of 250 and one of 75 cubic feet of air per minute), two air plug drills, two surfacers, 45 air hand tools, two cutting lathes for stones 20 feet by 3 feet 6 inches and 9 feet by 1 foot 10 inches, two polishing lathes for stones 20 by 5 feet and 10 by 3 feet, a stone saw (for use with chilled shot) for stones 15 by 8 by 7 feet, four polishers, a pneumatic Cavecchi polisher, and ten electric motors. Electric power is brought from Bolton and Middlesex Falls.

Transportation is by cart, 4 miles to Barre.

The product is used for monuments and memorial chapels. Specimens are the Robert Burns statue and pedestal, Barre, shown in Plate III, *A*; First North Dakota soldiers' memorial, St. Paul, Minn.; Indian massacre memorial, Serena, Ill.; Wade memorial chapel, Cleveland, Ohio; Hancock (canopy) memorial, San Francisco, Cal.; Doctor Kimball memorial, Concord, N. H.; General Thomas (shaft) memorial, Springfield, Ohio; Senator Dillon shaft, Davenport, Iowa.

ACME GRANITE QUARRY.

The Acme granite quarry is about 600 feet west-southwest of the Jones Light quarry, in Barre. (See Pl. I, No. 13.) Operator, C. N. Scott, East Barre, Vt.

The granite, "dark medium Barre," is a biotite granite of medium bluish-gray shade and even-grained fine texture.

The quarry consists of two openings, the smaller of which, made in 1905, is alone now in use. It measures about 20 feet N. 60° E. by 30 feet across and 10 to 25 feet in depth.

The sheets, 1 to 20 feet thick, dip 20° NNE. There are two sets of joints: (a), striking N. 50° to 55° E., dipping 65° to 90°, forms the south wall and a heading on the north wall; (b) strikes N. 35° W., is vertical, one only. The rift is reported as vertical and parallel to (a).

The plant comprises one horse derrick, two steam derricks, and a 45-horsepower hoisting engine, a large rock drill, and a steam pump.

Transportation is by siding, as shown on Plate I.

The product is used for monuments.

WETMORE & MORSE QUARRY.

The Wetmore & Morse quarry, 1,007 feet above the city, lies in a saddle about south-southeast of the top of Millstone Hill and about 200 feet below it. (See Pl. I, No. 14.) Operator, Wetmore & Morse Granite Company, Montpelier, Vt.

A. STATUE OF ROBERT BURNS AT BARRE, SHOWING ADAPTABILITY OF "BARRE GRANITE" TO SCULPTURE.

B. SHEET STRUCTURE AT SOUTHWEST FOOT OF BLACK MOUNTAIN IN DUMMERSTON ("BLACK MOUNTAIN QUARRY").

The sheets in the working face are thin and nearly horizontal; those higher up the dome are thicker and dip 30°-40° W.

The granite (specimen D, XXIX, 19, b), "light Barre," is a biotite granite of light, medium, slightly bluish gray shade (darker than that of the Jones Light quarry and that of Hallowell, Me., but lighter than that of Concord, N. H., "Concord granite") and of even-grained fine inclining to medium texture, with feldspar up to 0.3 inch and mica not over 0.1 inch. Its constituents, qualities, etc., are identical with those of specimen 18, a, from the Smith Upper quarry described on page 70. The quarry yields also some "medium."

The stone effervesces with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.49 per cent of CaO (lime) soluble in warm dilute (10 per cent) acetic acid, indicating a content of 0.87 per cent of $CaCO_3$ (lime carbonate, calcite), the presence of which mineral is also shown in thin section.

The quarry, opened about 1875, measures about 610 feet in a N. 60° E. direction by 100 to 200 feet across and from 50 to 75 feet in depth.

The sheets are from 1 to 28 feet thick. The quarry cuts the axis of the hill so as to show the arching of the sheets on the north-northwest wall. They are horizontal in the center at the top and dip 10° E. and W., but in the center at the bottom they dip 15° SSW., showing the dome structure of the hill. There are four sets of joints: (a) Striking N. 60° E., vertical and steep S. 22° E., forms part of the south-southeast wall; (b) striking N. 82° E., dipping almost 90°, forms part of the north-northwest wall; (c) striking N. 35° W., vertical, occurring only in the north half of the quarry, are coated with chlorite and sericite (one of these dies out on the south in such a slickensided plane dipping low south); (d) striking N. 30° E. and dipping 45° N. 60° W., greenish, slickensided. The quarry is somewhat difficult to work on account of scarcity of joints. The rift is reported as vertical with northeasterly course and the grain as horizontal. Rusty stain is up to 2 feet thick on upper sheets, but disappears entirely below.

The plant consists of two 60-ton, one 50-ton, and one 30-ton derricks, three electric hoisting engines of 55, 30, and 20 horsepower, an air compressor (capacity 840 cubic feet of air per minute) driven by a 150-horsepower electric motor, 10 large air rock drills, 15 air plug drills, and three steam pumps.

Transportation is by a siding, as shown on the map (Pl. I).

The product is used for monuments, 75 per cent of it reaching the market through local cutting sheds. Specimen: The J. D. Rockefeller monument at Cleveland, Ohio.

SMITH UPPER QUARRY.

The Smith Upper quarry, southwest of and below the last, is S. 32° W. of the top of Millstone Hill, in Barre. (See Pl. I, No. 15.) Operators, E. L. Smith & Co., Barre, Vt.

The granite (specimen D, XXIX, 18, a), "light Barre," is a biotite granite of light, medium, slightly bluish gray shade (darker than the "light" of the Jones quarry and that of Hallowell, Me., which are light inclining to medium gray, but lighter than that of Concord, N. H., which is medium gray) and of even-grained fine inclining to medium texture with feldspar up to 0.3 inch and mica not over 0.1 inch. Its constituents, in descending order of abundance, are: Clear, colorless to bluish translucent and milk-white potash feldspar (orthoclase, kaolinized and micacized, with a little fresh microcline); light smoky quartz with cavities in sheets with cracks parallel to or coinciding with them; translucent to milk-white soda-lime feldspar (oligoclase-albite more or less altered) rarely with flexed twinning planes; biotite (black mica), some of it chloritized and with epidote; a little muscovite or bleached biotite. Accessory: Pyrite, magnetite, titanite, apatite, zircon. Secondary: Calcite, generally in the orthoclase, kaolin, one or two white micas, chlorite, and epidote. It effervesces slightly with cold dilute muriatic acid.

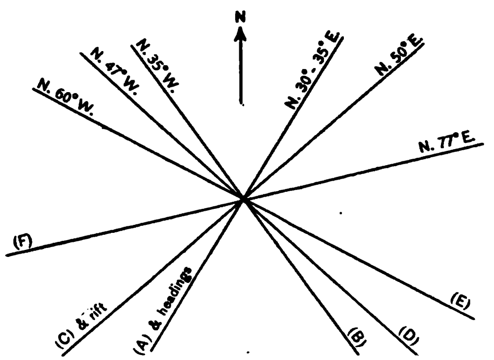

FIGURE 18.—Structure at Smith Upper, Smith Lower, and Duffee quarries.

The mineral contrasts are feeble.

The quarry is very irregular in outline, measuring about 400 feet in a N. 30° E. direction by 200 feet across and 30 to 60 feet in depth. The sheets, from 1 to 10, exceptionally 20 feet thick, are horizontal at the north end, but elsewhere bend over to the southwest 10° to 15°. Joint and rift courses of this and Duffee and Smith Lower quarries are combined in figure 18. There are two sets of joints: (A), vertical, forming headings on the northwest and southeast walls; (B), dipping 75° SW., is spaced 10 to 30 feet and over. The rift is reported as vertical and grain as horizontal. Rusty stain is from 1 to 18 inches thick, but there is little of it on the upper surfaces of sheets.

The plant for this and the two other Smith quarries comprises six 50-ton, four 20-ton, and four smaller derricks, an air compressor (capacity 1,800 cubic feet of air per minute), 10 hoisting engines, a Blondin carrier and engine, 25 large air rock drills, 40 air plug drills, and eight steam pumps. The firm's cutting plant at Barre includes two derricks, an overhead 20-ton crane, a hand crane, an air compressor (capacity 350 cubic feet of air per minute), four air plug drills, 50 air hand tools, three surfacers, three polishers, and two

electric motors (50 and 10 horsepower) for derricks, cranes, compressor, and polisher. Electricity is supplied by the Consolidated Lighting Company from falls on Winooski River, about 13 and 20 miles from Barre.

Transportation is by sidings, as shown on the map (Pl. I).

The product is monumental stone. Specimens of monuments from all the quarries of E. L. Smith & Co. are: Pedestal of equestrian statue of St. Louis, erected by W. R. Hodges in 1906, and Lemp mausoleum, St. Louis, Mo.; Cluett obelisk, with 44-foot shaft and pedestal, Troy, N. Y.; Smith obelisk, Old cemetery, Barre; the stone for Fleischmann mausoleum, Cincinnati.

DUFFEE QUARRY.

The Duffee quarry is west-northwest of and lower than the Smith Upper quarry and southwest of the top of Millstone Hill, in Barre. (See Pl. I, No. 16.) Operators, E. L. Smith & Co., Barre, Vt.

The granite (specimen D, XXIX, 17, a), "medium Barre," is a biotite granite of medium bluish-gray shade (a trifle darker than "Concord granite") and of even-grained fine texture with feldspars up to 0.2 inch and mica rarely to 0.1 inch. Its constituents, in descending order of abundance, are: Bluish translucent to milk-white potash feldspar (orthoclase, kaolinized and micacized, with a little fresh microcline); light smoky quartz with cavities in sheets and with cracks parallel to them, also showing optical effects of strain; translucent to milk-white soda-lime feldspar (oligoclase-albite, more or less altered), some of it with curving twinning planes; biotite (black mica), some of it chloritized; a little muscovite or bleached biotite. There are microscopic veins of epidote, of quartz, and of calcite. Accessory: Allanite, zircon, probably also magnetite and pyrite, although not in section. Secondary: Calcite, usually in orthoclase, kaolin, one or two white micas, epidote, quartz, chlorite. The stone effervesces slightly with cold dilute muriatic acid. The quarry produces some "dark" also.

The mineral contrasts are weaker than in the "dark" or in the "light" of the Jones or Smith Upper quarries, because of greater fineness of mica and more bluish cast of feldspar.

The quarry is estimated as about 400 feet east to west on one side and 300 on the other by 200 feet across and about 40 feet in depth.

The sheets, 2 to 12 feet thick, are somewhat regular, dipping 15° SW. with the rock surface. There are four sets of joints (see fig. 18): (A), dipping 75° S. 60° E., forms a 15-foot heading through the center of the quarry, and is spaced 10 to 100 feet; (B) dips 60° N. 55° E., one only in southwest part; (C) dips 60° S. 40° E., one on south wall; (D) dips S. 43° W., one on southeast wall. The rift is reported as vertical and the grain as horizontal.

The plant and product have been given in connection with the Smith Upper quarry, page 70. Transportation is by siding, as shown on Plate I.

SMITH LOWER QUARRY.

The Smith Lower quarry is west-northwest of the Duffee quarry near the foot of Millstone Hill and S. 60° W. from its top, in Barre. (See Pl. I, No. 17.) Operator, E. L. Smith & Co., Barre, Vt.

The granite, "medium Barre," is identical with that of the adjoining Duffee quarry described above. The quarry also yields some "dark."

The quarry is estimated as about 250 feet east to west by 200 feet across, and from 50 to 100 feet in depth.

The sheets, from 1 to 15 feet thick, dip 20° to 30° SW., but in the lower part is a mass 58 feet thick without sheets. Joint and rift courses are shown in figure 18: (A), dipping 80° S. 60° E., forms the east wall and a heading on the southwest wall, and recurs 20 feet south of the north wall; (B) dips 50° NNW. (two of this set, 8 feet apart, are in the southeast corner); (C) dips 40° N. 55° E., one only, discontinuous, on northeast wall. Rift and grain as at adjacent quarries.

The plant and product are given in connection with Smith Upper quarry. Transportation is by siding, as shown in Plate I.

SANGUINETTI QUARRY.

The Sanguinetti quarry is about three-fifths mile north of the top of Millstone Hill, in Barre. (See Pl. I, No. 18.) Operator, Joseph Sanguinetti, Barre, Vt.

The exact shade of biotite granite obtained here was not determined. The quarry was temporarily idle in 1907.

The quarry is about 100 feet by 50, and from 10 to 20 feet deep. The sheets, 8 to 10 feet thick, are imperfectly developed. Joints (a) strike N. 35° E., dip S. 55° E., and are spaced 10 to 20 feet; joints (b) strike N. 75° W., dip 65° to 80° S. 15° W., and are spaced 10 to 50 feet. There are some biotitic flowage streaks, also a pear-shaped concentrically banded mass 1 to 2 feet across. A schist outcrop between the quarry and railroad has a foliation strike north and a dip 55° W.

The plant consists of a derrick and small hoisting engine.

BOND & WHITCOMB QUARRY.

The Bond & Whitcomb quarry is N. 40° E. from the top of Millstone Hill and 200 feet below it, or 1,000 feet above the city, in Barre. (See Pl. I, No. 19.) Operators, Bond & Whitcomb, Barre, Vt.

The granite (specimen D, XXIX, 26, a), "coarse light Barre," is a biotite granite of light-gray shade, owing to more biotite a trifle darker than the "light" of Jones quarry, and of even-grained medium texture

with feldspars up to 0.3 inch, exceptionally 0.4 inch, and mica to 0.2 inch. Its constituents, in descending order of abundance, are: Clear colorless to milk-white potash feldspar (orthoclase, kaolinized and micacized, with a little fresh microcline, rarely inclosed by the former); light smoky quartz with cavities in sheets with rift cracks parallel to them, also showing optical effects of strain; whitish soda-lime feldspar (oligoclase to oligoclase-andesine) more or less altered; biotite (black mica), some of it chloritized; a little muscovite or bleached biotite. Accessory: Titanite. Secondary: Calcite, generally within the orthoclase, kaolin, one or two micas, chlorite. The stone effervesces with cold dilute muriatic acid.

This is a light constructional granite.

In a new opening a little north of the main one the stone (specimen D, XXIX, 26, b) "medium Barre," is a biotite granite of medium gray shade and fine texture with feldspars up to 0.2 inch, rarely 0.3 inch, and mica not over 0.1 inch. Its constituents are the same as in the coarser granite, excepting that the soda-lime feldspar is oligoclase and some of the orthoclase is fresh. The stone effervesces slightly with cold dilute muriatic acid.

This is a monumental granite.

The main quarry, opened in 1902, measures about 200 feet in a N. 35° E. direction by 150 feet N. 25° W., and is from 10 to 30 feet in depth.

The sheets are regular, 6 inches to 7 feet thick, and dip gently northeast. There are two sets of joints: (a) Striking N. 25° W., vertical, forms the northeast wall and a heading 75 feet from the southwest wall; (b) striking N. 35° E., vertical and steep N. 55° W., one only, forming the north wall. Some of the joint faces are coated with muscovite scales. The rift is reported as vertical with N. 35° to 40° E. course and the grain as horizontal. For spaces 1 to 2 inches wide the granite has very little biotite, and the average size of feldspars is there greater. A basic dike, described on page 56, runs parallel to the north wall and a little back of it. It is 2 feet thick but tapers out at heading (a). Rusty stain does not exceed 1½ inches on sheet surfaces.

The plant consists of two derricks, two hoisting engines, a small air compressor, three large rock drills, five air plug drills, and a siphon pipe.

Transportation is by siding, as shown on Plate I.

The product is used as dimension stone for buildings; that from the small opening is used for monuments.

BARNEY QUARRY.

The Barney quarry (formerly known as the Eclipse) is 360 feet north-northeast from the last and about N. 35° E. from the top of Millstone Hill, in Barre. (See Pl. I, No. 20.) Operator, Augusta Barney, Websterville, Vt.

The granite, "medium and light Barre," is a biotite granite of medium and light bluish gray shade and fine texture, like those already described.

The quarry is estimated as measuring about 300 feet in a northeast direction by 200 feet across and from 45 to 60 feet in depth.

The sheets, 1 foot to 3 feet 8 inches thick, are normal and dip about 10° NW. on the northwest side, but 10° SE. on the southeast side, with a S. 10° W. pitch of 10°, and they are slickensided in a S. 50° W. direction. Joints, rift, and dike courses are shown in figure 19. Joints (A), vertical, form a 3-foot heading on the southwest wall; (B) dip 80° N. 20° E., one only on southeast wall; (C) dip 40° N. 70° W., discontinuous, two near northeast wall, slickensided in direction of dip. There is a basic dike, up to 2 feet thick, at the south corner back of heading (A). The rock within the heading is crossed by horizontal subjoints 1 to 3 inches apart, due to the dike. On the northwest wall the granite is in contact with schist that has a foliation striking N. 20° E. and dipping steeply west. There is a pegmatite dike or lens along the schist contact, and the granite for a space of 15 feet from the contact is coarse and fine in alternating bands. There is also an inclusion of schist at the north corner, 15 feet by 1 foot, with a foliation striking N. 80° E.

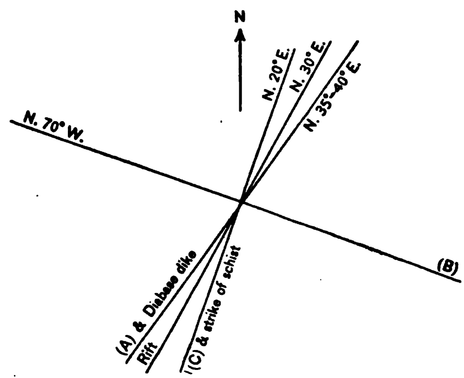

FIGURE 19.—Structure at Barney quarry, Barre.

The plant comprises a horse derrick, a steam rock drill, and a steam pump.

Transportation is by cart, 3½ miles to Barre.

The product is used for monuments.

CANTON QUARRY.

The Canton quarry is about 450 feet east-northeast from the Bond & Whitcomb quarry, and northeast of the top of Millstone Hill, in Barre. (See Pl. I, No. 21.) Operator, Barre Granite and Quarry Company, Barre, Vt.

The granite, "medium and light Barre," is a biotite granite of medium and light bluish-gray shade, like those already described.

The quarry is estimated as measuring about 300 feet in a northeasterly direction by 200 feet across, and from 35 to 60 feet in depth.

The sheets, from 1 to 14 feet thick, are normal and dip N. to 10°. There are two sets of joints: (a), striking N. 37° W. and dipping 80° N. 53° E., forms the east wall, and a heading on the west wall, and is spaced 5 to 50 feet; (b), striking N. 35° E., dipping 55° S. 55° E., is spaced 10 to 25 feet and 200 feet, and is slickensided in the direction of dip. The rift is reported as vertical with N. 42° E. course and the grain as horizontal. There are two quartz veins up to 1½ inches thick, one along heading (a), another in the middle of the quarry. A marked east-west compressive strain is shown in the faulting of channel cores as illustrated in figure 2.

The plant consists of two derricks, a four-drum hoisting engine, an air compressor (capacity 675 cubic feet of air per minute), four large rock drills, seven air plug drills, and two steam pumps.

Transportation is by siding. (See Pl. I.)

The product is used for monuments. Specimen: The soldiers' monument at Trenton, N. J.

O'HERIN QUARRY.

The O'Herin quarry is about 500 feet N. 35° E. of the Barney quarry, and in about that direction from the top of Millstone Hill, in Barre. (See Pl. I, No. 22.) Operators, Robert O'Herin & Co., Websterville, Vt.

The granite, "light Barre," is a biotite granite of light-gray shade like that previously described.

The quarry, opened in 1904, is estimated as measuring about 300 feet in a N. 22° E. direction by 150 feet across, and from 10 to 30 feet in depth.

The sheets, from 1 to 8 feet thick, are normal and dip very low southeast. There are two sets of joints: (a), striking N. 15° E., vertical, and dipping 55° E. on the southeast and northeast walls, is spaced 10, 20, to 100 feet; (b), striking N. 30° to 35° W., dipping 75° N. 60° E. and vertical, is discontinuous, one on and one near the south wall. The rift is reported as vertical with N. 30° E. course and the grain as horizontal.

The plant comprises one horse derrick, a large rock drill, an air plug drill, and a steam pump. Compressed air is obtained from the Barre Granite and Quarry Company.

Transportation is by cart, 3½ miles to Barre.

The product is used for monuments and buildings.

WALKER QUARRY.

The Walker quarry is east-southeast of the O'Herin quarry, and N. 40° E. from the top of Millstone Hill, in Barre. (See Pl. I, No. 23.) Operators, George Walker & Sons, Barre, Vt.

The granite, "medium Barre," is a biotite granite of medium gray shade and fine texture like that already described.

The quarry, opened in 1902, is estimated as measuring about 150 feet in a N. 30° E. direction by 80 feet across and 30 feet in depth.

The sheets, from 1 foot to 8 feet 10 inches thick, are normal and dip gently east and northeast. There are two sets of joints: (a), striking N. 25° W., vertical, forming east and west walls only; (b), striking N. 40° E., and vertical, adjacent to the dike. The rift is reported as vertical with N. 50° E. course and the grain as horizontal. A 12-inch basic dike, the continuation of that in Barney quarry, page 76, has the course of joints (b). The granite on the north side of this dike is broken into vertical scales, 1 to 6 inches thick and a foot wide.

The plant at the quarry comprises a horse derrick, a large air rock drill, two air plug drills, and an air pump. Compressed air is obtained from the Barre Granite and Quarry Company. The plant at the cutting shed in Barre includes a derrick, a hoisting engine, a 35-horsepower electric motor, and two air compressors (capacity 69 and 134 cubic feet of air per minute), two air plug drills, 25 air hand tools, a surfacer, and two polishers.

Transportation is by cart, 300 feet to rail for rough stock, but 3½ miles to cutting shed for stock to be finished.

The product is small monuments.

WELLS-LAMSON QUARRY.

The Wells-Lamson quarry is 640 feet above the city and about northeast from the top of Millstone Hill. (See Pl. I, No. 24.) Operator, The Wells-Lamson Quarry Company, Barre, Vt.

The granite, "light and medium Barre," is a biotite granite of light medium, slightly bluish gray shade, or of medium bluish-gray shade, and of even-grained fine inclining to medium or fine texture. It is reported as identical in quality with the "light" and "medium" of the Smith Upper and Duffee quarries described on pages 70, 71. The following result of a microscopic examination of "dark" granite from this quarry, made by Whitman Cross, of the United States Geological Survey, was published in 1898:[a]

> Messrs. Wells, Lamson & Co.'s dark granite is a fine, even-grained, typical granite containing two micas (biotite, muscovite) sometimes called granite proper. The constituents of importance are quartz, orthoclase, microcline, biotite, and muscovite The first three occur in wholly irregular grains interlocking in a very complex manner

[a] See Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, continued, 1898, p. 224.

The micas are in small leaves between and penetrating the other minerals to some extent. Muscovite apparently occurs in two forms, one corresponding to the biotite, as seemingly primary, and the other in small flakes in the orthoclase, and clearly a secondary mineral. Accessory constituents are oligoclase, albite (?), titanite (sphene), and apatite. There is an almost total absence of magnetite or other iron ore. Biotite is slightly changed to green, and probably yields chlorite in some samples. The orthoclase gives way to an aggregate of fine muscovite leaves, also varying much in different samples, no doubt. Both quartz and biotite show that the rock has endured considerable pressure, the former by the "undulatory extinction" it exhibits, and the biotite by the curved and bent lamellæ. The pressure did not extend to a crushing of the grains or any banded structure. In the feldspars is some calcite filling small cracks. On the basis of this examination I should estimate it at quartz 30 to 35 per cent, orthoclase 30 per cent, microcline 20 to 25 per cent. Much of the iron is present in the ferrous or unoxidized condition.

A chemical analysis of the "dark" from this quarry made by William C. Day at Swarthmore College, Pennsylvania, was published in the same work and on the same page, and is repeated here for reference.

Analysis of "dark Barre" granite by William C. Day.

SiO_2 (silica)	69.56
Al_2O_3 (alumina)	15.38
Fe_2O_3 (iron sesquioxide)	2.65
MgO (magnesia)	Trace.
CaO (lime)	1.76
Na_2O (soda)	5.38
K_2O (potash)	4.31
Mn (manganese)	Trace.
Loss on ignition, CO_2, and moisture	1.02
	100.06

Doctor Day also made the following physical determinations of "dark" and "medium" from this quarry:[a] Specific gravity, dark, 2.672; medium, 2.662; per cent of water absorbed, dark, 0.121 per cent; medium, 0.129 per cent; crushing strength, dark, 16,719 to 19,957 pounds; medium, 14,968 to 17,856 pounds.

The quarry, opened about 1885, is estimated as measuring about 400 feet in a N. 25° W. direction by 300 feet across and from 50 to 60 feet in depth.

The sheets, from 6 inches to 15 feet thick, dip gently southeast and N. 65° E. On the west side the lenses are very short. There is one sharply curving "toe nail" 10 feet high, intersecting the sheet structure. There are three sets of joints: (a), striking N. 65° to 70° E., dipping 40° to 60° N. 27° W., is spaced 25, 50, and 200 feet; (b), striking N. 30° E., vertical, forms a small heading on the south edge only; (c), striking N. 45° E., vertical, forms a heading on the north wall and is spaced 200 feet and over. The rift is reported as

[a] Op. cit., pp. 225, 226.

vertical (probably N. 30° E.) and the grain as horizontal. A 12-inch band of darker granite strikes N. 70° E. and dips 60° N. 20° W., marking the direction of the flow. Schist crops out close to the south wall and continues in that direction. A north-south compressive strain is reported.

The plant comprises a 100-ton and a 50-ton derrick, a 10-ton Blondin carrier, an air compressor (capacity 160 cubic feet of air per minute), six large rock drills, six air plug drills, and a steam pump.

Transportation is by siding, as shown on Plate I.

The product is used for monuments and buildings.

PRUNEAU QUARRY.

The Pruneau quarry is N. 75° E. from the top of Millstone Hill, in Barre. (See Pl. I, No. 25.) Operators, Pruneau & Co., Websterville, Vt.

The granite, "dark medium," is a biotite granite of medium bluish-gray shade and fine texture, in composition like those already described.

The quarry is estimated as measuring about 200 feet in a northwest direction by 200 feet across and from 30 to 45 feet in depth.

The sheets, from 6 inches to 9 feet thick, but thin for 10 feet down, are normal and dip 15° to 25° SSE. There are three sets of joints: (a), striking N. 10° to 15° E., dipping 65° S. 78° E., forms a heading in the south half of the quarry, and is spaced 5 to 30 feet; (b), striking N. 60° E., dipping 60° N. 30° W., forms the south wall and a 4-foot heading in the north half. It is slickensided in the direction of dip; (c), striking N. 65° W., vertical, usually crosses one sheet only. A heading of (a) is coated with a slickensided mass up to 1.75 inches thick, largely of coarse muscovite scales with some kaolinized feldspar, possibly of pegmatitic origin. The rift is reported as vertical with N. 30° E. course and grain as horizontal. A one-half inch quartz vein strikes N. 12° E. Several schist inclusions at the top of the northwest wall measure up to 8 by 2 feet.

The plant consists of a derrick and hoisting engine, hand derrick, small air compressor, large rock drill, three air plug drills and a steam pump.

Transportation is by cart, 3½ miles to Barre.

The product is used for monuments.

CONSOLIDATED MARR & GORDON QUARRY.

The Consolidated Marr & Gordon quarry is 860 feet above the city and N. 75° E. from the top of Millstone Hill, in Barre. (See Pl. I, No. 26.) Operator, Consolidated Quarry Company, Barre, Vt.

The granite, "light Barre," is a biotite granite of light medium slightly bluish shade like that of the Wetmore & Morse and Smith Upper quarries, and of even-grained fine inclining to medium texture. (See p. 70.)

The quarry is estimated as measuring about 300 feet from north to south by as much across, and from 50 to 70 feet in depth.

The sheets, from 1 to 15 feet thick, the thicker ones generally 5 to 10 feet, in places irregular, dip 15° E. There are four sets of joints, as shown in figure 20: (A) dips 35° N. 40° W., one on the west wall, and a heading at the southeast corner; (B) dips 75° W., one at the southeast corner; (C) dips 50° to 80° N. 20° W., forms north and south walls and small heading 30 feet west of the south wall; (D) dips 75° N. 60° E., one crosses the quarry from the northeast corner. The rift is reported as vertical and the grain as horizontal.

The plant consists of three derricks, two hoisting engines, an air compressor (capacity 600 cubic feet of air per minute), three large rock drills, three smaller ones, seven air plug drills, and a steam pump.

Transportation is by siding, as shown in Plate I.

The product is used for monuments, but stones with only one clear face go into buildings.

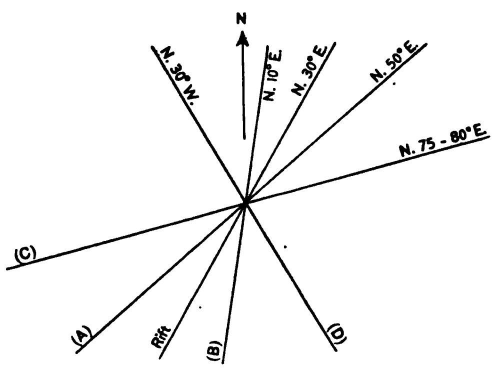

FIGURE 20.—Structure at Consolidated Marr & Gordon quarry Barre.

M'DONALD & CUTTER QUARRY.

The McDonald & Cutter quarry is east-northeast of top of Millstone Hill, east of the main street of Websterville, in Barre. (See Pl. I, No. 27.) Operator, Consolidated Quarry Company, Barre, Vt.

The granite of this and the four adjoining quarries of this firm is mostly "light Barre" with some "medium." It is a biotite granite of light medium or medium, slightly bluish-gray shade and of even-grained fine inclining to medium texture, like those described on pages 65, 71.

The quarry is estimated as measuring about 200 feet in a N. 22° W. direction by 175 feet across and from 65 to 110 feet deep.

The sheets, in places imperfectly developed, from 3 to 30 feet thick, undulate horizontally. There are masses 40 feet thick without sheets. There are three sets of joints: (a), striking N. 10° to 15° W., vertical, forms the east and west walls and is spaced 10 to 30

feet; (b), striking N. 40° to 45° E., vertical, is spaced 1 to 30 feet; (c) forms an irregular rusty heading at the northeast end, striking N. 15° E. and dipping 70° E., but undulating along the strike. "Sap" is up to 14 inches thick.

The plant of this and the four adjoining quarries of this firm comprises seven derricks, two Blondin carriers, nine hoisting engines, an air compressor (capacity 730 cubic feet of air per minute), seventeen large rock drills, twenty-eight air plug drills, and six steam pumps.

Transportation is by siding, as shown on Plate I.

The product is used for monuments, but stones with only one clear face are used for buildings.

INNES & CRUIKSHANK QUARRY.

The Innes & Cruikshank quarry is about 100 feet north-northeast of the last. (See Pl. I, No. 28.) Operator, Consolidated Quarry Company, Barre, Vt.

For the granite, see under that of the McDonald & Cutter quarry (p. 79).

The quarry is estimated as measuring about 350 feet in a north-northeast direction by 250 feet across and 90 feet in depth.

This is a "bowlder" quarry. The sheets, 2 to 12 feet thick, dip 45° NW., but some in the northeast part dip 25° E. and 35° NW. There are two sets of joints: (a), striking N. 80° to 85° E., dipping 50° to 70° S. 20° E., forms the southeast and part of the northwest walls, and is spaced 10, 30, 50, and 200 feet; (b), striking east-west, dipping 35° S., one only on southeast side. The rift is reported as vertical with N. 30° E. course and the grain as horizontal to 15° NW. Owing to erosion there is no parallelism here between the rock surface and sheet structure. Sand up to 2 inches thick occurs between the sheets, and the joints are also generally loose. The "sap" is from 6 to 16 inches thick.

For transportation and product, see those of the McDonald & Cutter quarry (above).

CAPITAL QUARRY.

The Capital quarry is 750 feet south-southeast of the McDonald & Cutter quarry and southeast of Millstone Hill, in Barre. (See Pl. I, No. 29.) Operator, Consolidated Quarry Company, Barre, Vt.

For the granite, see under that of the McDonald & Cutter quarry (p. 79).

The quarry is estimated as measuring 150 feet in a northeast direction by 100 feet across and 50 feet in depth.

This is a "bowlder" quarry. The sheets, from 6 inches to 4 feet thick, but extending to a depth of only 20 feet, dip about 10° SE.

There are three sets of joints: (a), striking N. 65° E., dipping 55° S. 25° E., spaced 3 to 10 feet, on south side only; (b), striking N. 35° E., dipping steep N. 55° W., is discontinuous; (c), striking NW., dipping 70° NE., is spaced 5 to 20 feet. A basic vertical dike, 2 to 6 feet thick, with northeast course, forms the northwest wall. It weathers spheroidally. The rift is reported as varying in different blocks.

For the plant, transportation, and product, see those of the McDonald & Cutter quarry (p. 80).

COUYELLARD QUARRY.

The Couyellard quarry is about 200 feet southeast of the McDonald & Cutter quarry and southeast of the top of Millstone Hill, in Barre. (See Pl. I, No. 30.) Operator, Consolidated Quarry Company, Barre, Vt.

For the granite, see under that of the McDonald & Cutter quarry (p. 79).

The quarry is estimated as measuring about 275 feet in a N. 70° E. direction by 200 feet across, and from 50 to 70 feet in depth.

This is a "bowlder" quarry. Sheet structure is hardly present. There are masses 20 feet thick. There are three sets of joints: (a), striking N. 75° E., dipping 65° S. 15° E., forms the north and south walls and one joint in the center; (b), striking northwest, dipping 45° NE., is spaced 5 to 20 feet and over; (c), striking N. 30° E., dipping 65° N. 60° W. to 90°, forms a heading at the east corner, and is spaced 5 to 40 feet and over. The rift is reported as vertical with N. 55° to 60° E. course, and the grain as horizontal.

The plant, transportation, and product are given in connection with the McDonald & Cutter quarry (p. 80).

M'IVER & MATHESON QUARRY.

The McIver & Matheson quarry is about 1,500 feet east-southeast of the Websterville main street, and in same direction from the top of Millstone Hill, in Barre. (See Pl. I, No. 31.) Operators, McIver & Matheson, Barre, Vt.

The granite, "light and medium Barre," is a biotite granite of light medium and medium bluish-gray shade, and of even-grained fine inclining to medium texture like that described on pages 65, 71.

The quarry is estimated as measuring about 250 feet in a northeast direction by 200 feet across and from 30 to 65 feet in depth.

This is a "bowlder" quarry. The sheet structure is very irregular, owing to "growing on." There are two sets of joints: (a), striking northwest, vertical, forms a 15-foot wide heading across the middle of the quarry, and is spaced 4 to 44 feet; (b), striking N. 40° E., ver-

tical, is spaced 10 to 50 feet. A diabase dike, the continuation of that in Jones Light quarry (p. 56), is here 9 feet thick, vertical and parallel to joint (b). The granite for a foot next to the dike breaks off in vertical scales, 1 to 6 inches thick. The rift is reported as vertical with N. 40° E. course and the grain as horizontal. Rusty stain is 12 inches thick along joint and some sheet faces.

The plant includes a derrick and hoisting engine, a large rock drill and a steam pump.

Transportation is by cart, either 4 miles to Barre or a few hundred feet to a siding at an adjoining quarry.

The product is used for monuments. Specimens: The Governor Goebel monument in Kentucky and the Holthaus monument at St. Louis, Mo.

MANUFACTURERS' QUARRY.

The Manufacturers' quarry, south of and adjoining the last, is in Barre. (See Pl. I, No. 32.) Operator, Manufacturers' Quarrying Company, Barre, Vt.

The granite, "medium Barre," is a biotite granite of medium bluish-gray shade and of even-grained fine texture. (See p. 71.)

The quarry is estimated as measuring 250 feet in a northwest direction by 200 feet across and from 50 to 60 feet in depth.

This is a "bowlder" quarry. The sheets, in places 1 to 10 feet thick, die out laterally in the center of the quarry, so that masses 30 feet thick can be obtained at the same level as thin-sheeted ones. There are three sets of joints: (a), striking N. 40° W., vertical, is spaced 8 to 30 feet; (b), striking N. 80° E. to 80° W., dipping 75° S. and 90°, is spaced 30 feet and over; (c), striking N. 15° E., vertical, is spaced 30 to 100 feet. The rift is reported as vertical, with N. 50° to 60° E. course, and the grain as horizontal. There are three schist inclusions on the southeast wall, measuring 25 by 10 by 10 feet; 20 by 8 by 8 feet; and 3 by 2 feet. The foliation of the largest strikes N. 30 W. The schist is injected with minute dikes of granite and the granite within 7 feet of the inclusion is slightly darker. One of the (a) joints is coated with quartz over an inch thick with large scales of muscovite probably of pegmatitic origin. Rusty stain is 12 inches thick on sheet surface, but 24 inches on joint faces.

The plant comprises a 30-ton derrick, a hoisting engine, a Blondin carrier and engine, a small air compressor, three large rock drills, seven air plug drills, and a steam pump.

Transportation is by siding, as shown on Plate I. The product is monumental granite, but the waste is used for paving and curbing.

BARRE QUARRY.

The Barre quarry is N. 40° E. from the McIver & Matheson quarry, 800 feet northeast of the southern road from East Barre to Websterville, and about four-fifths of a mile east of the top of Millstone Hill, in Barre. (See Pl. I, No. 33.) Operator, Barre Quarry Company, Barre, Vt.

The granite, "light and medium Barre," is a biotite granite of light medium and medium bluish-gray shade and even-grained fine inclining to medium texture. Its feldspars are slightly more bluish than those of the corresponding shades from the other quarries.

The quarry, opened in 1905, measures about 100 by 60 feet and 30 feet in depth.

This is a "bowlder" quarry, without sheet structure. There are two sets of joints: (a), striking N. 30° E., vertical; (b) striking N. 65° to 75° E., dipping 40° to 50° S. 25° E., forms the north and south walls and is spaced 3 to 50 feet. The rift is reported as varying in different blocks. Biotitic knots are 1.5 by 0.5 inches. There is "sap" up to 6 inches thick on joint faces.

The plant comprises a derrick, an electric motor, an air compressor (capacity 200 cubic feet of air per minute), and a steam pump.

Transportation is by cart, over 4 miles to Barre.

The product is used for monuments and buildings.

MILNE QUARRY.

The Milne quarry is on the south side of the southern road from Websterville to East Barre and about nine-tenths of a mile east-southeast of top of Millstone Hill, in Barre. (See Pl. I, No. 34.) Operator, Alexander Milne, Barre, Vt.

The granite, "light and medium Barre," is a biotite granite of light medium and medium bluish-gray shade, and of even-grained fine inclining to medium texture. (See pp. 65, 71.)

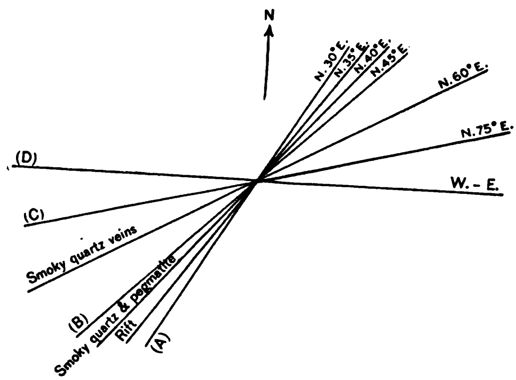

FIGURE 21.—Structure at Milne quarry, Barre.

The quarry is estimated as measuring about 250 feet in a north-northwest direction by 250 feet across and from 55 to 70 feet in depth.

The sheets, from 1 to 6 feet thick, are about horizontal or dip 20° E., but disappear 25 feet below the rock surface, where low-dipping joints (D) are used by the quarrymen instead. There are four sets of joints, as shown in figure 21: (A), vertical, dipping 20° and 40° N. 60° W., forms the east-southeast wall, is spaced 3 to 150 feet, coated with coarse scales of muscovite; (B), dipping 40° northwest, discontinuous, is spaced 15 to 150 feet; (C), dipping 70° S. 15° E., is spaced 2 to 20 feet and over, but stops 20 feet down; (D), dipping 75° S., one only, at the south corner. The rift is reported as vertical with N. 35° E. course and the grain as horizontal. There are veins of smoky quartz up to 2 inches thick in the south corner, at intervals of about 3 feet, dipping 60° S. 40° E. Some with another strike are part pegmatite. The microscopic structure of this quartz has been described on page 55.

The plant comprises two derricks, a hoisting engine, an air compressor (capacity 200 cubic feet of air per minute), four large rock drills, six air plug drills, and a steam pump.

Transportation is by cart, over 4 miles to Barre.

The product is used for monuments and buildings.

BARRE MEDIUM QUARRY.

The Barre Medium quarry is about 500 feet southeast of the Milne quarry. (See Pl. I, No. 35.) Operator, Barre Medium Granite Company, Barre, Vt.

The granite, "medium and light Barre," is a biotite granite of medium and light medium bluish-gray shade and even-grained fine inclining to medium texture like that described on pages 65 and 71.

The quarry, opened in 1906, is estimated as measuring 200 feet north-south by 150 feet across and from 10 to 25 feet in depth.

Sheets from 6 inches to 5 feet thick, increasing in thickness downward, dip low southeast. No joints have yet been found. The rift is reported as vertical with N. 60° E. course, and the grain as horizontal. Rusty stain is up to 4 inches thick on sheet surfaces.

The plant comprises a derrick, a hoisting engine, an air compressor driven by a 20-horsepower engine, two large rock drills, four air plug drills, and a steam pump.

Transportation is by cart, over 4 miles to Barre.

The product is used for buildings and monuments. Specimen of the "light:" The trimmings in the Aldrich public library, Barre, Vt.

EMPIRE GRANITE COMPANY'S QUARRY.

The Empire Granite Company's quarry is about 800 feet east-southeast of the Milne quarry on the north side of the southern road from Websterville to East Barre. (See Pl. I, No. 36.) Operator, Empire Granite and Quarrying Company, Northfield, Vt.

The granite, "light and medium Barre," is a biotite granite of light medium and medium, slightly bluish-gray shade, and of even-grained fine inclining to medium texture. (See pp. 65, 71.)

The quarry, opened about 1889, is estimated as about 375 feet by 200 and from 10 to 50 feet deep.

The sheets are normal, from 1 to 16 feet thick, dipping 10° SE. There are two sets of joints: (a), striking N. 70° E., dipping 53° S. 20° E., is spaced 10 to 50 feet and over; (b), striking northwest, dipping 75° SW., discontinuous, is spaced 100 feet and over. The rift is reported as vertical with N. 35° E. course and the grain as horizontal. The "sap" is up to 3 inches thick. At a smaller opening (not being worked) the sheets dip about 10° N. 60° E. and are also normal.

The plant comprises two derricks and two hoisting engines, an air compressor (capacity 650 cubic feet of air per minute), two large rock drills, five air plug drills, and a steam pump.

Transportation is by cart, over 4 miles to Barre.

The product is used for monuments and buildings.

STRATTON QUARRY.

The Stratton quarry is 400 feet east of the last, and about 1¼ miles east-southeast of the top of Millstone Hill, in Barre. (See Pl. I, No. 37.) Operator, George Stratton Quarry Company, Barre, Vt.

The granite, "light and medium Barre," is a biotite granite of light medium and medium gray shade, and of even-grained fine inclining to medium texture like that previously described.

The quarry, opened in 1905, measures about 100 feet square and averages 10 feet in depth.

The sheets, from 1 to 5 feet thick, vary from horizontal to a dip of 10° about south. There is but one set of joints, which strikes N. 65° E., dips 55° S. 25° E., and is spaced 1 to 20 feet. The "sap" is 6 inches thick and under.

The plant consists of one horse derrick.

Transportation is by cart, over 4 miles to Barre.

The product is used for buildings and monuments.

JONES DARK QUARRY.

The Jones Dark quarry is in Williamstown (Orange County), but adjoins the Empire quarry in Barre. (See Pl. I, No. 38.) Operators, Jones Brothers & Co., Barre, Vt.

The granite (specimen D, XXIX, 13, a), "dark Barre," is a biotite granite of dark bluish-gray shade, a trifle darker than that of the Bruce quarry, and of even-grained fine inclining to medium texture with feldspars up to 0.3 inch and mica to 0.1 inch. Its constituents

are identical with those of the Milne & Wylie quarry stone described on page 59. It effervesces with cold dilute muriatic acid.

The polished face shows pyrite and a little magnetite. The polish is fair. Its cut hard-way face is as light as that of the "light Barre," and thus in marked contrast to its polished face. Its mineral contrasts and qualities are identical with those of the Milne & Wylie quarry stone (p. 59), but its texture, particularly its mica, appears to be a little finer.

The quarry, opened about 1886, is estimated as measuring about 300 feet in a N. 80° E. direction by 250 feet across and from 50 to 100 feet in depth.

The sheets, 2 to 20 feet thick, are irregular and undulating. There is one mass 28 feet thick. There are four sets of joints: (a), striking N. 80° E., vertical, forms headings on north and south walls, is spaced 5 to 30 feet, and has rusty faces; (b), striking N. 15° W., vertical, usually discontinuous vertically, is spaced 10, 20, 30, and 200 feet; (c), striking east-west, dipping 55° S., discontinuous, one only in south part; (d), striking N. 50° to 55° E., dipping 37° S. 37° E., forms a small heading north of the south wall. The rift is reported as vertical, with course of about N. 55° E., and the grain as horizontal. A schist inclusion in the west wall is 30 feet long with a foliation striking N. 50° E. There are also masses of darker granite of roundish outline up to 3 feet in diameter, like those in the Marr & Gordon quarry (p. 62). Rusty stain is up to 6 inches thick on sheet surfaces.

The plant comprises a 20-ton and a 30-ton derrick, two hoisting engines, an air compressor (capacity 700 cubic feet of air per minute), four large rock drills, 12 air plug drills, and two steam pumps.

Transportation is by siding to the cutting shed at Barre, which is on another siding. (See Pl. I.)

The product is monumental granite. Specimens are included in the list on page 67.

JONES SMALL DARK QUARRY.

Jones Small Dark quarry is over 100 feet S. 20° W. from the last, in Williamstown. (See Pl. I, No. 39.) This is an old opening which was being worked anew in 1907. Operators, Jones Brothers & Co., Barre, Vt.

The granite is identical with that of the last quarry. The sheets are very irregular. Joints (A) and (B) of the other quarry recur. There is a schist inclusion, 4 by 2 feet in the north wall. The darker granite also occurs here, but associated with irregular masses of aplite (specimen D, XXIX, 14, a) of light medium bluish-greenish gray color, and very fine even-grained texture described more fully on page 55.

PIRIE QUARRY.

The Pirie quarry is in Williamstown (Orange County), nearly 1½ miles south-southwest of the top of Millstone Hill. (See Pl. I, No. 40.) Operator, James K. Pirie, Graniteville, Vt.

The granite, "dark Barre," is a biotite granite of dark, slightly bluish gray shade and of even-grained fine inclining to medium texture like that of the Barre quarries described on page 58.

The quarry, opened in 1882, is estimated as measuring 350 feet in a northeast direction by 100 and 250 feet across, and from 30 to 100 feet in depth.

The sheets are normal, from 1 to 12 feet thick, and dip 10° to 30° NNW. Joint, rift and dike courses are shown in figure 22. Joint set (A) dips 60° S. 27° E., forms part of the west wall, and a rusty heading across the center of quarry; (B) dips 55° S. 55° E., forms the east wall, is spaced 1 to 20 and over 50 feet. This is also very rusty; (C) dips 55° E., only three, spaced 10 feet; (D), about vertical, discontinuous, is spaced 30 feet. The rift is reported as vertical and the grain as dipping about 35° N. 30° W. A 3 foot 6 inch pegmatite dike dipping 65° S. 25° E. crosses the center of the quarry and sends out tapering branches up to a foot in length. (See, further, p. 55.) "Sap" up to a foot thick is mostly confined to the underside of sheets.

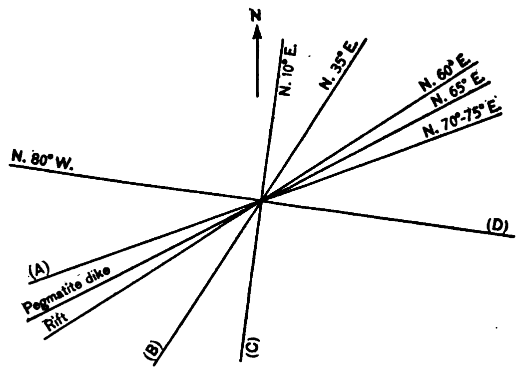

FIGURE 22.—Structure at Pirie quarry, Williamstown, near Barre.

The plant comprises four derricks, four hoisting engines, an air compressor (capacity 565 cubic feet of air per minute), four large air rock drills, 14 air plug drills, and three steam pumps.

Transportation is by siding, as shown on Plate I.

The product is used for monuments. Specimens: Soldiers and Sailors' monument, Bennington, N. Y.; columns and capitals for the Flood mausoleum, San Francisco; memorial to persons killed by flour-mill explosion, Minneapolis, Minn.

WHEATON QUARRY.

The Wheaton quarry is 2½ miles east of the city, 620 feet above it, and north-northwest of the top of Cobble Hill, in Barre. (See fig. 12.) Operator, Barre White Granite Company, Barre, Vt.

The granite (specimen D, XXIX, 29, a), "white Barre," is a biotite granite of very light-gray shade (lighter than "light Barre" and as light as that of North Jay, Me.), and of even-grained medium texture, with feldspars up to 0.4 inch and mica to 0.2 inch. Its constituents, in descending order of abundance, are: Bluish translucent to milk-white potash feldspar (orthoclase, kaolinized and micacized, with a little fresh microcline); light smoky quartz with hairlike crystals of rutile, and with cavities in sheets with rift cracks parallel to them, intersected at right angles by shorter and fewer sheets of cavities; whitish soda-lime feldspar (oligoclase-albite) more or less altered; biotite (black mica) more sparse than in "Barre granite" generally, some of it chloritized; a little muscovite or bleached biotite. Accessory: Titanite, zircon, apatite, rutile. Secondary: Calcite, largely in orthoclase, kaolin, one or two white micas, chlorite. The stone effervesces with cold dilute muriatic acid.

This is a constructional granite of very light shade, medium texture, and strong mineral contrasts.

The quarry is estimated as about 325 feet north-south by 325 feet across and from 5 to 20 feet deep. It was opened on a surface rising 50 feet in 325.

The sheets, 1 to 4 feet thick and normal, dip 10° NW. and NNE. There are two sets of joints: (a), striking, N. 70° to 85° E., vertical, is spaced 2 to 200 feet and over; (b), striking N. 20° E., vertical, forms a heading on the south side.

The plant comprises a derrick and hoisting engine and two smaller hand and horse derricks.

Transportation is by cart, 2½ miles to Barre.

The product was used for buildings and the bases of monuments.

The quarry not operated in July, 1907.

WILDBUR QUARRY.

The Wildbur quarry is on the west side of Cobble Hill, 600 feet above the city and N. 35° E. from the top of Millstone Hill, in Barre. Operators, Wildbur Brothers & Bessey, Barre, Vt.

The granite (specimen D, XXIX, 31, a), "light Barre," is a biotite granite of light medium gray shade (like Jones "light Barre") and of even-grained fine inclining to medium texture, with feldspars up to 0.2 inch and mica to 0.1 inch. The mica is finer and more abundant than in the stone of Wheaton quarry. Its constituents are identical with those of Jones "light Barre" described on page 65. A clear microcline incloses an altered orthoclase. The quartz shows effects of strain and conspicuous rift cracks parallel to or coinciding with sheets of cavities. Some of these cracks polarize brightly and continue into the feldspars, where they are clearly filled with fibrous muscovite. The stone effervesces with cold dilute muriatic acid.

The quarry is estimated as measuring 100 feet east-west by 75 feet across. It has a working face 80 feet high on the east.

The sheets, 1 to 8 feet thick, becoming thicker eastward, appear to belong to the outside of an arch or dome striking here N. 10° to 20° W. and dipping 60° S. 75° W. One set of joints only, striking N. 75° E. and dipping 70° S. 15° E., is spaced 8 to 30 feet and over. The rift is reported as vertical, with N. 75° E. course, and the grain as horizontal.

The plant consists of a derrick and hoisting engine.

Transportation is by cart, 3 miles to Barre.

The product is used for monuments and buildings.

BIANCHI QUARRY.

The Bianchi quarry is on the west side of Cobble Hill near its southwest end, about 600 feet above the city (southwest to Bond & Whitcomb quarry on Millstone Hill), in Barre. Operator, Charles B. Bianchi, East Barre, Vt.

The granite, "light Barre," is a biotite granite of light medium gray shade and of even-grained fine inclining to medium texture, identical with that of the Wildbur quarry (p. 88).

The quarry measures about 70 feet north-south by 60 feet across, and has a high working face on the east.

The sheets, 10 to 18 feet thick, strike N. 40° W., and dip 35° S. 50° W. There are two sets of joints: (a), striking N. 50° E., vertical, is spaced 1 to 20 feet; (b), striking N. 30° W., vertical, discontinuous, is spaced 10 to 30 feet. The rift is reported as vertical with N. 50° E. course and the grain as horizontal. Flow structure shown by vertical biotitic planes strikes about north. A basic dike, up to 6 inches thick, crosses the center of the quarry with N. 55° E. course.

The plant consists of a horse derrick. The firm has a cutting plant in Barre, which receives granite mostly from other quarries.

Transportation is by cart, 3 miles to Barre.

The product is used for bases and hammered monumental work.

HYLAND QUARRY.

The Hyland quarry is in Barre, on the west side of Cobble Hill, a little north of the Wildbur quarry and at the same level. It was just being opened in July, 1907.

Besides the above quarries a number of openings shown on the quarry map (Pl. I) were either temporarily or permanently abandoned in 1907.

CABOT.

The town of Cabot adjoins that of Woodbury on the southeast and of Walden on the northeast. Lambert's prospect is in the northern corner of the township, on the east side of a north-south ridge, roughly about 4 miles east of Robeson Mountain in Woodbury and about 700 feet above Woodbury Pond. (See fig. 1.) It is on the farm of Myron Goodnough, near the Walden line, on the South Walden road which leads from Cabot to Hardins. Operator, Joseph Lambert, Macksville, Hardwick, Vt.

The granite (specimen D, XXIX, 59, a), dark gray, is a quartz monzonite of dark bluish gray color (as dark as "dark Barre") and of even-grained fine texture, with feldspars and mica up to 0.2 inch, the latter rarely 0.3 inch. Its constituents, in descending order of abundance, are: Clear quartz with fluidal and other cavities in sheets and with rift cracks parallel to them filled with fibrous muscovite and extending into the feldspars; bluish gray to milk-white soda-lime feldspar (oligoclase) but little kaolinized, micacized, and with calcite; bluish-gray potash feldspar (orthoclase, kaolinized and micacized, with microcline); greenish biotite (black mica); and a little muscovite or bleached biotite. Accessory: Pyrite, titanite, apatite, and allanite (a crystal 0.33 by 0.09 millimeter rimmed with epidote). Secondary: Calcite, epidote, kaolin, and one or two white micas. It effervesces slightly with cold dilute muriatic acid.

This stone is a little finer textured than some of the "dark Barre," and more micaceous. Its mineral contrasts are more marked owing to its feldspars being whiter and less bluish, and its quartz not smoky. It ought to hammer light.

The quarry, opened in 1904, consists of several small preliminary openings. A little work was done in 1907.

The sheets are not yet sufficiently exposed to show their thickness. There are five sets of joints: (a), striking N. 85° E., dipping 75° N.; (b), striking N. 55° W., dipping 55° S. 35° W.; (c), striking N. 65° E., dipping 25° NNW.; (d), striking N. 5° E., vertical; (e), striking N. 60° E. and dipping 75° S. 30° E.

CALAIS.

GENERAL STATEMENT.

The town of Calais adjoins that of Woodbury on the southwest. The quarries are at Adamant (formerly known as Sodom) in the west corner of the town and 6 miles north-northeast of Montpelier. (See fig. 1.) The quarries lie along a N. 30° E. line on the southeast side of a granite ridge. The granite is a biotite granite of medium and light-gray shade and fine texture. Of geologic interest is the

absence of sheet structure and the occurrence of graphite in connection with quartz veins. Schist crops out below the quarries at the village with a foliation striking N. 20° E. and dipping 55° W.

PATCH QUARRY.

The Patch quarry is within one-half mile of Adamant, in Calais. Operators, Patch & Co., Montpelier, Vt.

The granite (specimen D, XXIX, 52, a) "medium gray," is a biotite granite of medium, slightly bluish gray color and of even-grained medium texture, with feldspars up to 0.3 inch, rarely 0.4 inch, and mica up to 0.1 inch. The larger feldspars are crystallized about the quartz and mica and give the stone something of a porphyritic texture. Its constituents, in descending order of abundance, are: Clear colorless potash feldspar (orthoclase, somewhat kaolinized and micacized, with microcline) with inclusions of the other constituents; clear, colorless quartz with but few cavities; bluish to milk-white soda-lime feldspar (oligoclase-albite more or less altered); biotite (black mica); and a little muscovite or bleached biotite. Accessory: Apatite, zircon. Secondary: Kaolin, calcite, and white mica. It effervesces slightly with cold dilute muriatic acid.

This granite is of the same shade as "medium Barre" but of less bluish and more greenish tinge. Its mineral contrasts are stronger and its texture a little coarser. Its large clear feldspars give brilliancy to its rough surface.

The quarry, opened about 1893, is estimated as measuring 250 feet from north to south by 150 feet across and from 20 to 50 feet in depth.

Sheet structure is absent. There are two sets of joints: (a), utilized as sheets in quarrying, striking N. 85° E., dipping 50° S., is spaced 2 to 17 feet and slickensided in a southwest direction; (b), striking like (a) but dipping 40° N. to 90°, is spaced 20 to 75 feet, in places discontinuous. The rift is reported as striking N. 30° E. and dipping 50° N. 60° W., and the grain as striking and dipping as joints (a). The "sap" is 4 inches thick on joint faces. A small vein of smoky quartz parallel to joints (a) contains large limonite particles from the alteration of some iron mineral. The slickensided face of this vein is graphitic.

The plant comprises three 20-ton derricks, a hoisting engine, an air compressor (capacity 250 cubic feet of air per minute), five air plug drills, and a large rock drill.

Transportation is by cart, 7 miles to Montpelier.

The product is used for monuments and finds a market chiefly in the Middle West.

LAKE SHORE QUARRY.

The Lake Shore quarry is about 1,200 feet S. 32° W. from the Patch quarry near Adamant in Calais. Operator, Lake Shore Quarry Company, Montpelier, Vt.

The granite (specimen D, XXIX, 53, a), "gray granite," is a biotite granite of light inclining to medium gray shade and of even-grained fine texture with feldspars up to 0.2 inch and mica to 0.1 inch, rarely 0.2 inch. The larger feldspars are crystallized about the quartz and mica, giving the stone something of a prophyritic texture. Its constituents are identical with those of the Patch quarry stone, except that it contains secondary epidote in particles up to 0.5 millimeter. It effervesces slightly with cold dilute muriatic acid.

This stone is a trifle darker than "light Barre" and a trifle lighter than "medium Barre." Its shade corresponds to that of the granite of Hallowell, Me., but its contrasts are stronger. Its other qualities are identical with those of the Patch quarry stone.

The quarry, opened in 1902, is about 300 feet long in a N. 60° W. direction by 250 feet across and from 20 to 40 feet deep.

Sheet structure is undeveloped. There are three sets of joints: (a), utilized as sheets in quarrying, striking N. 80° E., dipping 80° S., is spaced 1 to 18 feet; (b), striking N. 75° E., dipping 30° N. 15° W., only two on south wall; (c), striking N. 20° E., dipping 30° W., discontinuous, at intervals of 20 feet and over. The rift is reported as having a N. 20° E. course and dipping 70° N. 20° W. A 3-inch quartz vein is parallel to joints (a).

The plant comprises a derrick, hoisting engine, air compressor (capacity 200 cubic feet of air per minute), a large rock drill, three air plug drills, and a pulsometer pump.

Transportation is by cart, 7 miles to Montpelier.

The product is used for monuments and buildings. Specimen: The Soldiers' Memorial building, Stowe, Vt.

EUREKA QUARRY.

The Eureka quarry is about 900 feet N. 30° E. from the Patch quarry, near Adamant in Calais. Operator, Eureka Granite Company (Clark Sibley), Montpelier, Vt.

The granite is presumably identical with that of the Patch quarry.

The quarry is about 350 feet from east to west by 80 feet across, with a working face on the north 105 feet high.

Incipient sheet structure is from horizontal to inclined 20° S. There is only one set of joints, and that strikes N. 75° E. and dips 55° S. 15° E.; spacing 2 to 10 feet. A quartz vein with limonite is parallel to the joints.

The plant comprises a derrick, hoisting engine, air compressor, large rock drill, and two air plug drills.

Transportation is by cart, 7 miles to Montpelier.

The quarry was temporarily idle in 1907.

WOODBURY.

TOPOGRAPHY.

The township of Woodbury lies northeast of Calais, northwest of Cabot, and southwest of Hardwick. Its principal quarries are on the southeast flank of Robeson Mountain, about a mile east of Woodbury Center and 3 miles north-northeast of Woodbury (Sabins) Pond. (See map, fig. 8.) Robeson Mountain is a ridge about a mile long with an axis curving from N. 80° E. to S. 70° W. Its top is from 300 to 400 feet above the hollows on either side and 930 feet above Woodbury Pond and about 1,100 feet above the railroad at Hardwick. Granite has also been quarried on the ridges on the northwest and southeast sides of Buck Pond, and is now quarried on the rising ground at the head of the hollow on the north side of Robeson Mountain. This mass is continuous with the ridge southeast of Buck Pond. Granite has also been quarried on the north and northeast foot of Nichols Ledge, a bold cliff about 3 miles N. 70° E. from Robeson Mountain and 740 feet above Woodbury Pond, in the east corner of the town east of Nichols Pond. The granite masses referred to are all within an area of about 3½ miles square, occupying the northeast part of the town.

GENERAL GEOLOGY.

Little is known of the geology of Woodbury. In the Vermont report of 1861 all the central and eastern part of the town appears as "calciferous mica schist." A belt of "clay slate" is represented as crossing the west part of the town in a north-northeast direction. Schist crops out on the northwest side of Robeson Mountain with a bedding strike of N. 70° W. and vertical dip and north pitch; also on the west-southwest side with a N. 67° E. strike and a dip of 55° N. 23° W. This would indicate a synclinal structure for the schist of this mountain. Schist also crops out near the quarries on the rising land north of the mountain, and appears also to cap the ridge east of the north end of Buck Pond. This is a muscovite-quartz-biotite schist with interbedded calcareous quartzite. The contact of schist and granite on Robeson Mountain has been described on page 23. The mountain appears to be an oblong dome in structure with an east-northeast to west-southwest axis, the sheets of which, horizontal at the top, bend over to 15° to 20° on the northwest and southeast sides, although in places still covered by schist. Nichols ledge is another

conspicuous granite mass. The granite of the top is coarsely porphyritic with feldspars an inch long, but at its north and northeast foot there is a granite of very fine to fine texture, possibly a dike in the coarser. All the granite masses evidently protrude through the schist, but what parts of the intervening hollows are still occupied by schist is not determined. The foliation of a schist mass back of the Webber quarry, between Buck Pond and Robeson Mountain, strikes N. 20° E.

"WOODBURY GRANITE."

The "Woodbury granites" are all biotite granites of more or less bluish gray shade, ranging from dark to light (one very light cream color), and in texture from very fine to medium. They fall into four kinds, but, taking account of minor differences, into nine varieties. Most of them possess in large masses one general characteristic: They carry sparse, more or less incomplete, crystals up to an inch across of clear potash feldspar formed about the other minerals. There is some parallelism between these crystals, for seen at a certain angle the cleavage planes of adjoining crystals reflect the light alike.

The granites of Robeson Mountain vary from light to medium gray shade and from medium to fine, inclining to medium, porphyritic texture. Their constituents, in descending order of abundance, are: (a) Clear to translucent bluish potash feldspar (orthoclase and microcline), rarely somewhat kaolinized, its large particles with inclusions of biotite, quartz, and soda-lime feldspar; light to medium smoky quartz with hairlike crystals of rutile and fluidal and other cavities in sheets in two rectangular sets parallel to rift and grain cracks, respectively (some of the rift cracks extend into the feldspars and are filled with fibrous muscovite); milk-white soda-lime feldspar (oligoclase to oligoclase-albite), more or less kaolinized, micacized, and with calcite and in places epidote; biotite (black mica), some of it chloritized; a little muscovite or bleached biotite. Accessory: Pyrite, titanite, zircon, apatite, rutile. Secondary: Kaolin, a white mica, epidote, zoisite, calcite, limonite. Some of the feldspars are minutely intergrown with quartz in vermicular structure.

Two estimates of mineral percentages by the Rosiwal method average as follows:

Average estimate of mineral percentages in granite of Robeson Mountain.

Feldspar	64.35
Quartz	29.15
Mica	6.48

One chemical test (p. 97) shows it to contain 0.16 per cent of CaO (lime), soluble in warm dilute (10 per cent) acetic acid, indicating a content of 0.28 per cent of $CaCO_3$ (lime carbonate, calcite).

A. CARVED PANEL (8 BY 12 FEET) OF WOODBURY GRAY GRANITE FLANKING ENTRANCE OF COOK COUNTY COURT-HOUSE, CHICAGO.

B. SHEET STRUCTURE AT FLETCHER QUARRY ON ROBESON MOUNTAIN, WOODBURY.

Looking southwest. One set of sheets curves southeasterly, dipping as high as 30°; another set of sheets or close joints intersects the first, dipping 5°–10° S. 70° W.

The general differences between the three varieties of granite on Robeson Mountain are these: In the stone from the Fletcher quarry the feldspar and quartz areas are rather large and well defined by differences of shade. In the stone from the Woodbury Lower quarry the quartz areas are finer, fewer, and less smoky. In the "Bashaw" the texture is finer and contrasts weaker than in either of the others.

The fine dark gray of the new Drenan and Webber openings and of another near Buck Pond (pp. 102–104) is of dark bluish-gray shade and fine texture, with feldspars to 0.2 inch and mica to 0.1 inch. Its composition is identical with that of the granite of Robeson Mountain, but its quartz is clear and its feldspar is albite to oligoclase-albite. Its general shade is like that of "dark Barre," but its texture is finer.

The stone from the Nichols Ledge quarry is of light inclining to medium bluish-gray shade and of very fine to fine texture, with feldspar to 0.15 and mica to 0.1 inch, with a few larger porphyritic clear feldspars. This is lighter and finer than the last. Its quartz is clear with apatite needles and its second feldspar is oligoclase to oligoclase-andesine.

Finally, there is the very light, slightly cream-colored constructional granite of the prospect between Robeson Mountain and Buck Pond (p. 103), which is of medium texture and speckled with black. Its quartz is smoky.

The minor differences, which make the varieties in the granites described above, will appear in the detailed descriptions of the stone of each quarry.

GEOLOGY OF WOODBURY QUARRIES.

The usual range in thickness of sheets is from 2 to 8 or 20 feet; the extremes are 1 to 40 feet. The double sheet structure at the Fletcher quarry has already been described on page 17 and is shown in Plate IV, *B*. The secondary, nearly horizontal, set is from 5 to 9 feet thick. It recurs in the lower part of main quarry of the Woodbury Granite Company. There is a northeast to southwest compressive strain at the Fletcher quarry near the axis of the mountain, parting and extending the upper sheets.

The joints divide themselves into six sets: (a), striking N. to N. 10° E., with its complementary set; (b), N. 85° to 90° E.; (c), striking N. 20° to 30° E., with its complementary set; (d), N. 50° to 65° W.; (e), striking N. 20° to 30° W., with its complementary set (f), N. 60° to 65° E. The spacing of these joints ranges from 2 to 200 feet, but mostly 10 to 20 to 40 feet. Headings, 3 to 30 feet wide, of set (a) are spaced 30 to 50 feet on Robeson Mountain. The rift is reported as vertical with courses of N. 15°, 26°, 35°, and 60° E., and the grain as uniformly horizontal. At one quarry the rift has to be followed closely in winter, but the rock is reported as splitting with equal facility in any direction in summer.

Flow structure appears with a dip of 50° SW. There is an irregular banding at the old Drenan quarry caused by unequal distribution of biotite. The schist capping is exposed at another of the Drenan openings, and the 100-foot mass of schist at the back of the Webber quarry is either part of the same or a very large inclusion. The schist inclusions on Robeson Mountain, 25 and 8 feet long, have been referred to on page 100. A small light-greenish calcareous inclusion at the Ainsworth quarry proves to be chiefly crystalline calcite with quartz particles under 0.1 millimeter, together with apatite and secondary epidote and zoisite, and has veinlets of epidote, quartz, and calcite. This appears to have originally been a quartzose marble, and its interest lies in its evidence of the presence of calcareous rocks here prior to the granite intrusion.

There are biotitic segregations up to 2 feet in diameter. Small pegmatite dikes at the Chase quarries, near Buck Pond, strike about north, and a 4-inch quartz vein on the northwest side of Robeson Mountain strikes N. 35° to 40° E.

FLETCHER QUARRY.

The Fletcher quarry is on Robeson Mountain near its west-southwest end and on its southeast side, in Woodbury. (See fig. 8.) Operator, E. R. Fletcher, Hardwick, Vt.

The granite (specimens D, XXIX, 56, a, c), "Woodbury gray," is a biotite granite of light-gray shade (between "light Barre" and the granite of Hallowell, Me.) and of medium texture with feldspars up to 0.3 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Clear to translucent bluish potash feldspar (orthoclase, some of it minutely intergrown with plagioclase, also microcline), the larger particles with inclusions of biotite and soda-lime feldspar; medium smoky quartz with hairlike crystals of rutile and cavities in two sets of rectangular sheets with rift and grain cracks parallel to them; milk-white soda-lime feldspar (oligoclase-albite) much kaolinized, somewhat micacized and epidotized, and with calcite; biotite (black mica) some of it chloritized; and a little muscovite or bleached biotite. Accessory: Pyrite, titanite, zircon, apatite, rutile. Secondary: Kaolin, a white mica, epidote, zoisite, calcite, limonite.

An estimate of the mineral percentages by the Rosiwal method yields these results with a mesh of 0.5 inch and a total linear length of 46.5 inches:

Estimated mineral percentages in granite of Fletcher quarry, Woodbury.

Feldspar	63.11
Quartz	31.22
Mica	5.67
	100.00

The average diameters of the particles by the same calculation are: Feldspars (adding 20 per cent to number for plagioclase), 0.103 inch; quartz, 0.1 inch; mica, 0.029 inch.

The stone effervesces very slightly with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.16 per cent of CaO (lime) soluble in warm dilute (10 per cent) acetic acid, which indicates a content of 0.28 per cent of $CaCO_3$ (lime carbonate, calcite), the presence of which mineral is also shown by the microscope.

This is a brilliant granite with marked mineral contrasts. The quartz and feldspar areas are rather large and well defined. The polish is poor owing to the large size of the micas. The polished face shows some pyrite.

The quarry, opened about 1887, is estimated as measuring 300 feet in a northwest direction or across the ridge, by 300 along it, and from 20 to 40 feet in depth. It is practically the beginning of a cross section of the ridge and dome.

The complex sheet structure here has already been described (p. 17) and is shown in Plate IV, *B*. The primary sheets, 1 to 5 feet thick, are horizontal at the northwest and upper side of the quarry, but gradually bend over and dip 20° to 30° SE. at the lower southeast side. The secondary set, 5 to 9 feet thick, dips 5° to 10° about W. across the other. There are three sets of joints: (a), striking N. 30° E., vertical, is spaced 6 to 30 feet and over; (b), striking N. 65° E., dipping 75° N. 25° W., one only in southeast part; (c), striking N. 20° W., vertical, is spaced 2 to 15 feet. There are no headings. Some of the joint faces are greenish probably from chlorite. The rift is reported as vertical with N. 35° E. course and the grain as horizontal. Flow structure consists of biotitic streaks of irregular course. Biotitic knots from 1 to 3 inches across are reported. There is a marked northeast-southwest compressive strain in the upper part of the quarry, raising the sheets and even forming new sheet partings. There is no rusty stain whatever on sheet surfaces.

The plant comprises, at the quarry two derricks (one of them of 40 tons) and a large rock drill; at the cutting shed at Hardwick a 10-ton and a 15-ton derrick, a hoisting engine, a 10-ton locomotive crane, a 40-horsepower engine, and three polishers.

Transportation is effected by siding from the Hardwick and Woodbury Railroad, which brings the stone 8 miles to the cutting shed, and to the St. Johnsbury and Lake Champlain Railroad. (See fig. 8.)

The product is used for monuments and buildings. Specimens: Base of the General Sherman monument, Washington, D. C.; Home-

wood Cemetery entrance, Allegheny, Pa.; Crandall monument, Crandall Park, Glens Falls, N. Y. (this is a pentagonal shaft 36 feet by 4 feet 10 inches by 5 feet); base courses, approaches, and steps to post-offices at Atlantic City, N. J., and Jacksonville, Ill.

WOODBURY GRANITE COMPANY'S QUARRIES.

The Woodbury Granite Company's quarries are on Robeson Mountain, roughly from 1,400 to 2,100 feet N. 80° E. from the Fletcher quarry, in Woodbury. (See fig. 8.) Operator, Woodbury Granite Company, Hardwick, Vt.

The granite is of two sorts. Specimen D, XXIX, 57, b and c, "Woodbury gray," is a biotite granite of medium gray shade and medium texture with feldspar up to 0.3 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Clear to bluish translucent potash feldspar (microcline and orthoclase) somewhat kaolinized; light smoky quartz with hairlike crystals of rutile, and cavities in sheets with rift and grain cracks parallel to or coinciding with them; milk-white soda-lime feldspar (oligoclase) considerably kaolinized but not micacized or epidotized, in places intergrown with quartz in vermicular structure; biotite (black mica); and a little muscovite or bleached biotite. Accessory: Pyrite, apatite, zircon, rutile. Secondary: Kaolin and zoisite. Carbonate and epidote were not detected. There is no effervescence with cold dilute muriatic acid.

An estimate of the mineral percentages by the Rosiwal method with a mesh of 0.3 inch and a total linear length of 38.1 inches yielded these results:

Estimated mineral percentages in granite in Woodbury Granite Company's lower quarry.

Feldspar	65.6
Quartz	27.1
Mica	7.3
	100.0

The average diameters of all the particles by the same calculation is 0.084 inch; that of the feldspar (adding 20 per cent to the number for the plagioclase as in calculation for average diameter), is 0.105 inch; quartz, 0.074 inch; and mica, 0.025 inch.

This stone to the eye is like that of the Fletcher quarry, except that its quartz particles are a little finer, less numerous, and less smoky. Its mineral contrasts are, therefore, weaker. The polish is poor, owing to abundant and rather large mica scales, but the contrasts on the polished face are strong. It shows a little pyrite.

The other sort (specimens D, XXIX, 57, a and d), "Woodbury Bashaw," is a biotite granite of medium-gray shade (about like that

of "Concord granite" but more bluish and with more contrasts), and of fine inclining to medium texture with feldspars up to 0.2 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are: Clear to translucent bluish potash feldspar (microcline and orthoclase), light smoky quartz with cavities in two sets of rectangular sheets, with rift and grain cracks parallel to them, respectively. The rift cracks extend into the feldspars and are filled with fibrous muscovite; milk-white soda-lime feldspar (oligoclase) much micacized with epidote and calcite, also intergrown with quartz in vermicular structure; biotite (black mica), some of it chloritized; a little muscovite or bleached biotite. Accessory: Pyrite, zircon crystals, apatite. Secondary: A white mica, epidote, calcite, chlorite. The stone effervesces slightly with cold dilute muriatic acid.

This is a monumental granite. Its mineral contrasts are not as marked either in the rough or the polish as in the "Woodbury gray." This is due to the feldspars being less kaolinized and thus less white. Its texture is finer and it polishes better. The polished face shows a little pyrite.

Three compression tests of the "Woodbury gray" made for the firm at the United States Arsenal at Watertown, Mass. (test No. 13261), yielded these results:

Compressive strength of "Woodbury gray" granite.

	Pounds per square inch.
First crack, 199,000 pounds; ultimate strength	22,460
First crack, 181,000 pounds; ultimate strength	19,850
First crack, 168,000 pounds; ultimate strength	20,110
Average	20,806

The quarries consist of four openings: The main and western one, made in 1880, beginning at the south foot of the ridge, extends about 500 feet along it and 400 feet northward up its side, with an average depth of 50 feet. The "upper quarry," above and north of the main one, is about 200 feet square, and its north side is at the top of the hill nearly 300 feet higher than the lower edge of the main quarry. The third opening, about 800 feet east of the main one, made in 1906, is about 125 by 70 feet and from 10 to 30 feet deep. This produces the finer monumental granite, "Woodbury Bashaw," described on page 98. The fourth is a small opening made in 1907, about 200 feet northwest of the third.

The sheets at the top of upper quarry and of the ridge are horizontal. In the third opening they are from 2 to 13 feet thick, ill defined, and about horizontal. In the main quarry they range from 2 to 18 feet, exceptionally 23 feet and even 40, curving over from the horizontal to dip 20° S. They are intersected by a horizontal

set. (See pp. 17, 97.) The joint courses (shown in fig. 23) are four: (A) dips 60° to 65° N., 35° E. (some vertical, discontinuous), spaced 20 to 40 and 200 feet; (B), vertical or dipping 75° W., discontinuous along the dip, in third opening spaced 10 to 30 feet, but in main quarry mostly headings, five in all, 3 to 30 feet wide and 30 to 50 feet apart; (C) is vertical, discontinuous, and much more open than (A) or (B); (D) is spaced 2 and 10 to 40 feet. The rift is reported as vertical and the grain as horizontal, but not marked. The rift has to be followed closely in winter, but in summer the rock splits almost any way. There are two schist inclusions in the main quarry, 25 by 10 feet and 8 feet by (?), also some smaller ones. Rusty stain measures from 1 to 18 inches on sheet surfaces.

The plant at the quarries comprises a 75-ton, a 50-ton, three 40-ton, a 30-ton, and two 20-ton derricks, seven hoisting engines, three Blondin carriers with two engines and cables 1,200, 800, and 700 feet long to carry waste to the dumps in the valley, an air compressor (capacity 1,160 cubic feet of air per minute), five large rock drills, twenty-four air plug drills, and eight hollow-steel drills ("bull machines") for blowing out powdered granite. The plant at the cutting sheds at Hardwick comprises three derricks, two overhead 20 and 40 ton cranes, an outdoor overhead traveling 30-ton crane operated on a trestle 575 feet long and of 75-foot span to facilitate storage of finished stones and rapid loading of cars, two air compressors (capacity 1,000 and 500 cubic feet of air per minute), eleven air plug drills, 65 air hand tools, six surfacers, a polisher, four lathes for stones 35 by 4 feet, 13 feet by 2 feet 6 inches, 12 by 2 feet, and 13 feet by 1 foot, two polishing lathes for stones 25 by 5 and by 3 feet, two saws for stones 10 by 8 by 6 feet and 16 by 6 by 7 feet, two MacDonald combined planers and surfacers. The firm in 1908 was engaged in equipping its electric power station with a 4-foot tubular steel penstock to secure a higher head, and two motor generator sets of capacity of 250 kilowatts each. The power line was being extended 6 miles to the quarry plant, in order to run it by electricity also and do away with steam engines.

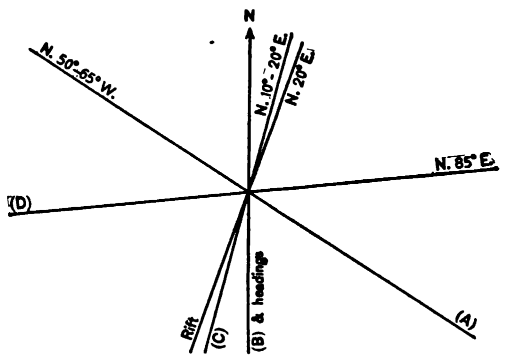

FIGURE 23.—Structure at Woodbury Granite Company's quarries, on Robeson Mountain.

Transportation is by siding from the Hardwick and Woodbury Railroad (see fig. 8), which brings the stone 8 miles to the cutting shed, and the St. Johnsbury and Lake Champlain Railroad.

The product is used both for buildings and monuments. Specimens of buildings: Pennsylvania capitol, Harrisburg; Cook County court-house, Chicago; base course and 36 interior polished columns of Kentucky capitol, Frankfort; post-office and custom-house, Providence, R. I.; Carnegie Library, Syracuse, N. Y.; Homeopathic Hospital, Pittsburg, Pa.; Bank of Ohio Valley, Wheeling, W. Va.; Hotel Pontchartrain, Detroit, Mich.; Mandell residence, Boston, Mass. Specimens of monuments: Soldiers and sailors' monument, Scranton, Pa.; soldiers' monument, Manchester, Vt.; memorial archway, Port Huron, Mich.; and the Flower memorial, Watertown, N. Y. The adaptability of the granite for carving is shown in Plate IV, *A*, representing a panel on the Cook County court-house.

CARSON QUARRY.

The Carson quarry is on the northeast foot of Robeson Mountain, in Woodbury. (See fig. 8.) Operators, Carson Brothers, Woodbury, Vt.

The granite is a biotite granite similar to that of the main quarry of the Woodbury Granite Company, page 98.

The quarry was barely opened in 1907. The sheets are thick.

Transportation is by cart, one-third of a mile to the Hardwick and Woodbury Railroad.

AINSWORTH QUARRY.

The Ainsworth quarry is on the northeast foot of Robeson Mountain, in Woodbury, about 1,000 feet northeast of the railroad. (See fig. 8.) Operators, Ainsworth & Ainsworth, Woodbury, Vt.

The granite is a biotite granite similar to that of the main quarry of the Woodbury Granite Company, page 98.

The quarry consists of two openings: One 50 by 35 feet and 15 feet deep; the other, about 500 feet west of the first, is 50 by 20 and 10 feet deep.

The sheets are from 15 to 20 feet thick. There are very dark gray knots up to 2 feet by 1 foot, with half-inch porphyritic feldspars, much fine biotite, and not a little pyrite. A small inclusion of fine-grained quartzose marble was noticed on page 96.

The plant comprises a hand and a horse derrick.

The stone has to be carted 1,000 feet or more to rail. The quarry is not worked in haying time.

MILLER QUARRY.

The Miller quarry is about 500 feet west-southwest of the last. Operator, G. F. Miller, Woodbury, Vt.

This is a small opening of recent date. A flow structure dipping 50° SW. was noticed.

DRENAN QUARRIES.

The Drenan quarries are in Woodbury, on the rising land north of the east end of Robeson Mountain, and about 150 feet above the north spur of the Hardwick and Woodbury Railroad. (See fig. 8.) Operators, Drenan, Brown & Raycraft, Woodbury, Vt.

The granite of the new opening now worked (specimen D, XXIX, 65, a), "Woodbury fine dark gray," is a biotite granite of dark bluish-gray shade and fine texture with feldspar up to 0.2 inch and mica to 0.1 inch, but with some large clear sparse feldspars formed about the other minerals. As many of these have their cleavage parallel, the rough rock face seen at a certain angle has a brilliant sheen. Its constituents, in descending order of abundance, are clear colorless to translucent potash feldspar (microcline and orthoclase) slightly kaolinized, with inclusions of biotite, quartz, and soda-lime feldspar; clear, colorless quartz with cavities in sheets; bluish milk-white soda-lime feldspar (albite to oligoclase-albite) kaolinized and micacized, also with calcite; biotite (black mica); and a little muscovite or bleached biotite. Accessory: Pyrite, apatite, zircon. Secondary: Kaolin, a white mica, calcite, zoisite. The stone effervesces with cold dilute muriatic acid.

This is a monumental granite of the same shade as "dark Barre" but of finer texture. It is darker than any of the granites of Robeson Mountain.

The quarry consists of three openings, two of which are abandoned. The last, made in 1907, is 200 by 100 feet and shallow.

The structure at the new opening is insufficiently exposed. Rift is reported as vertical with N. 60° E. course and the grain as horizontal. The area of this fine granite is said to measure about 200 feet square, with coarser granite around it. At one of the older openings, a few hundred feet south, a medium gray granite is banded with a less biotitic, very light gray granite (specimen D, XXIX, 65, b). This is even grained and fine textured, with feldspar up to 0.2 inch and mica to 0.05 inch. Its quartz is very pale smoky; its feldspar very light cream color. The second feldspar is oligoclase-albite, kaolinized and micacized and with some grains of epidote and zoisite. There are dark biotitic knots 12 by 6 inches. At the third opening, a few hundred feet west of that last described, the granite is capped on the west by schist 20 feet thick.

The plant consists of three hand derricks, an air compressor (capacity 125 cubic feet of air per minute) run by a gasoline engine.

LIGHT GRANITE PROSPECT.

Within a few hundred feet west of the old Drenan openings there is a considerable ledge which has been prospected for building granite. This is a biotite granite of very light, slightly buff or cream-tinted gray shade, and of medium texture with feldspars up to 0.3 inch and with sparse black mica to 0.15 inch. Its quartz is pale smoky. The mica is in strong contrast to the quartz and feldspar.

WEBBER QUARRIES.

The Webber quarries are in Woodbury, still farther north of Robeson Mountain, on a mass which is continuous with that on the southeast side of Buck Pond. (See figure 8.) Operator, Webber Granite Company, Hardwick, Vt.

The granite of the main and older opening (specimen D, XXIX, 68, a), "Woodbury gray," is a biotite granite of light bluish-gray shade and of medium inclining to fine texture, with feldspars up to 0.3 inch and mica to 0.15 inch. It is slightly more bluish and finer textured than the gray of the main quarry of the Woodbury Granite Company and lighter in shade than their "Bashaw," and a trifle darker than "light Barre." Its constituents, in descending order of abundance, are: Clear to bluish translucent potash feldspar (microcline and orthoclase), slightly kaolinized with inclusions of biotite, quartz, and soda-lime feldspar; light smoky quartz with hairlike crystals of rutile and cavities in sheets; milk-white soda-lime feldspar (oligoclase-albite) kaolinized and micacized and with calcite, with rims radially intergrown with quartz; biotite (black mica), some of it chloritized; a little muscovite or bleached biotite. Accessory: Magnetite, rutile. Secondary: Kaolin, a white mica, calcite, chlorite, epidote. There is scarcely any effervescence with cold dilute muriatic acid.

The stone of an opening made in 1907 (specimen D, XXIX, 67, a), "Woodbury fine dark gray," is a biotite granite of dark bluish-gray shade and of fine texture with feldspar up to 0.2 inch and mica to 0.1 inch, and with sparse clear porphyritic feldspars up to 0.3 inch, with inclusions of quartz and mica. This granite, as to its constituents, is identical with that of the Drenan quarry (specimen 65, a) described on page 102, and it has the same peculiar sheen. Its soda-lime feldspar is oligoclase-albite. It effervesces in cold dilute muriatic acid.

This is a monumental granite of dark bluish-gray color corresponding to "dark Barre" but of finer texture.

The main opening is about 150 feet in a N. 65° W. direction, by 75 feet across, and from 10 to 25 feet deep.

The sheets, 8 feet thick, are horizontal or dip northwest. There are four sets of joints: (a), striking N. 60° to 65° W. and vertical,

forms the northeast wall, is spaced 50 feet; (b), striking N. 25° to 30° W. and vertical, is discontinuous; (c), striking N. 60° E. and vertical, forms the northeast and southwest walls; (d), striking N. 20° E. and vertical, discontinuous, is spaced 25 feet and over. The rift is reported as vertical with N. 15° E. course and the grain as horizontal. There is a mass of mica slate on the east wall 100 feet long and 10 feet wide with a foliation striking N. 20° E. and dipping 55° E. It is veined by granite.

The plant comprises one hand and two horse derricks, an air compressor (capacity 110 cubic feet of air per minute), a large rock drill, and three air plug drills.

Transportation is by a siding from the Hardwick and Woodbury Railroad.

FRYATT & CARR PROSPECT.

Fryatt & Carr, of Woodbury, in 1907 were quarrying bowlders and possibly surface sheets a little south of the Webber quarries near the railroad switch on the south side of the track.

BUCK POND QUARRIES AND GRANITES.

Between the southwest end of Buck Pond and the new Webber quarry, roughly 500 feet north of the latter, is an abandoned quarry of biotite granite of dark bluish-gray shade and fine texture (specimen D, XXIX, 69, a) identical with specimens 65, a, and 67, a, of the new Drenan and Webber openings described on pages 102, 103. (See fig. 8.) The sheets, 5 to 8 feet thick, dip gently south. There is an east-west working face 100 feet long and 35 feet high without headings. Two sets of joints strike east and north, respectively.

On the southeast side of the pond, possibly 1,000 feet roughly northwest of the above quarry and on the west side of a granite ridge, is another abandoned opening. The rock (specimen D, XXIX, 70, a) is a biotite granite of light bluish-gray shade but of medium texture, with feldspar to 0.3 inch. It is more bluish than any of the granites of Robeson Mountain. Its texture is slightly coarser than that of the old opening of the Webber quarry (specimen 68, a), and also than the granites on the other side of the pond.

CHASE QUARRIES.

The Chase quarries are on the first high bluff northwest of Robeson Mountain, over 500 feet northwest of Buck Pond and 200 feet above it. (See fig. 8.) They have been idle for several years. The stone is a biotite granite of light bluish-gray shade and medium inclining to fine texture, identical with specimen 68, a, of the Webber main quarry described on page 103. There is a working face on the west 150 feet long and 40 feet high. The sheets, up to 8 feet thick, dip

gently northeast. Pegmatite dikes, 2 inches thick, cross the granite beyond the face with 30° W. dip.

Near the southwest end of the pond, but on the west side of its outlet and on the ridge, are two small recent openings. One was operated by Elmer Leach. The granite is of dark bluish-gray shade and medium inclining to fine texture. It resembles that of the Webber and Chase quarries, but is darker. The sheets, from 4 to 5 feet thick, are about horizontal.

NICHOLS LEDGE CARTER QUARRY.

The Nichols Ledge Carter quarry is at the northeast foot of Nichols Ledge in the east corner of the town of Woodbury. It is near the A. Dutton house, now occupied by A. D. Kimball. (See fig. 8.) Operator, J. H. McLeod, Hardwick, Vt. It was not worked in 1907.

The granite (specimen D, XXIX, 61, b) is a biotite granite of light inclining to medium bluish-gray shade and of fine to very fine texture, with feldspars up to 0.2 inch and mica to 0.1 inch, also with larger porphyritic clear feldspars formed about the other minerals. It is finer textured than the stone of the new Drenan and Webber openings (pp. 102, 103) and of lighter shade. Its constituents, in descending order of abundance, are clear, colorless potash feldspar (orthoclase and microcline); clear quartz with apatite needles and some cavities in sheets; bluish to milk-white soda-lime feldspar (oligoclase to oligoclase-andesine), but little kaolinized; olive-colored biotite (black mica) and a little muscovite or bleached biotite. Some of the feldspar is minutely intergrown with quartz. Accessory: Titanite, apatite. Secondary: Kaolin, epidote, calcite. It does not effervesce with cold dilute muriatic acid.

The sheets are up to 2 feet thick. There are some biotite knots. A similar granite is reported as once quarried by L. C. Fisher on the north side of Nichols Ledge.

WINDHAM COUNTY.

DUMMERSTON.

GENERAL STATEMENT.

The Dummerston granite area lies 5 and 6 miles north-northwest of Brattleboro and is shown on the state geologic map of 1861 as surrounded by "calciferous mica schist," with a belt of "clay slate" east of it along the Connecticut. The quarries and prospects are in the southwest part of the town on the sides of Black Mountain, and also half a mile south-southwest of it. Black Mountain, as shown on the United States Geological Survey reconnaissance topographic map (Brattleboro sheet), is on the east side of West River, 4 miles west of Connecticut River. This is a roundish granite mass, probably of

dome structure, a square mile in area, and from 900 to 950 feet above West River, and 1,269 feet above sea level. The sheets on its southwest side dip 30° to 40° about west, and in its northwest part, about 350 feet above the river, 30° N. 30° W. As shown in Pl. III, *B*, a mass of sheets, about 35 feet thick at the foot of the mountain, does not appear to be normally related either in the thickness of its sheets or their attitude to the sheets above it. These thin sheets may either be of more recent origin than the others, or may be separated from them by a fault. The effect of compressive strain upon sheets in part of this quarry has been referred to on page 25 and illustrated in Plate VIII, *B*, of Bulletin 354.

The granites of Dummerston are quartz monzonites of very light gray and light bluish-gray shade and of even-grained medium or medium inclining to fine texture.

BLACK MOUNTAIN QUARRY.

The Black Mountain quarry is at the southwest foot of Black Mountain, three-fourths mile south-southeast of the village of West Dummerston, in Dummerston, and 5 miles north-northwest of Brattleboro. Operator, George E. Lyons Company, West Dummerston, Vt.; main office, Monson, Mass.

The granite, of two sorts, chiefly "West Dummerston white" (specimen D, XXIX, 90, b), is a quartz monzonite of very light gray shade, speckled with bronze-colored mica (muscovite and biotite), and of even-grained medium texture, with feldspars up to 0.3 inch and mica to 0.1 inch. Its constituents, in descending order of abundance, are clear to pale smoky quartz, showing effect of strain, with hairlike crystals of rutile and a few fluidal cavities in sheets; milk-white soda-lime feldspar (oligoclase to oligoclase-albite), some of it with flexed twinning planes, kaolinized and micacized; clear potash feldspar (microcline and orthoclase); muscovite and less biotite apparently intergrown and bent or twisted with fibrous muscovite stringers extending out from them into and between the other particles. Accessory: Apatite, rutile. Secondary: Kaolin, white micas, epidote, zoisite, calcite. There are crush borders about the quartz and feldspar particles.

This stone effervesces slightly with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.07 of CaO (lime) soluble in warm dilute (10 per cent) acetic acid, which indicates a content of 0.125 per cent of $CaCO_3$ (lime carbonate, calcite), the presence of which mineral is also shown by the microscope.

A compression test, made on a 4-inch cube at the United States Arsenal at Watertown, Mass., in 1905, showed the first crack at

308,000 pounds, and an ultimate compressive strength of 27,810 pounds per square inch.

This is a building granite of medium grain and very light shade, between that of North Jay, Me., and that of Bethel, Vt., in whiteness.

The other granite (specimen D, XXIX, 90, a), "dark blue," is a quartz monzonite of light inclining to medium bluish-gray color, and of even-grained fine inclining to medium texture with feldspars up to 0.2 inch and mica to 0.1 inch. Its constituents are identical with those of the "white" specimen 90, b, but its oligoclase-albite is bluish and less altered, and its mica nearly all muscovite. It shows less calcite in thin section and does not effervesce with cold dilute muriatic acid.

This is a monumental granite of light bluish-gray tint and without mineral contrasts.

The quarry, opened about 1877, is estimated as measuring about 1,200 feet in a N. 20° W. direction along the base of the mountain, by 200 feet across and from 15 to 50 feet deep.

The sheets for a thickness of 25 to 35 feet above the road level, and for a length of 100 feet, are from 6 inches to 2 feet thick, and are horizontal or slightly inclined west. (See Pl. III, *B*.) Below the road level they measure up to 14 feet in thickness and dip 20° W., although horizontal for short spaces. Above this thin-sheeted mass they dip 30° to 40° W., and are considerably thicker. At the north end of the quarry compressive strain forms new thin sheets and parts them. (See p. 17.) There are two sets of joints: (a), striking N. 15° E., vertical, is spaced 7 to 30 feet; of (b), striking N. 20° W., dipping 80° N. 70° E., there is only one, at the south end. Flow structure strikes N. 22° E. and dips 80° N. 80° W. The rift is reported as vertical with N. 15° E. course and parallel to the mica plates, and the grain as horizontal. Both are good. Pegmatite dikes from 0.25 to 3 inches thick, with large light bluish-gray unstriated feldspars, strike N. 10° E., etc. The light bluish granite occupies 350 feet of the north end of the quarry, the rest of it being "white." Knots are rare and up to 6 inches across. Rusty stain, up to 3 inches wide on the upper sheets, is generally absent from the lower ones.

The plant comprises thirteen derricks, one of them of 20 tons, five hoisting engines, an air compressor, four large rock drills, a channel bar drill, and four air plug drills.

Transportation is by two sidings from the Vermont Central Railway. Stones for finishing are shipped to the firm's cutting plant, at Monson, Mass.

forms the northeast wall, is spaced 50 feet; (b), striking N. 25° to 30° W. and vertical, is discontinuous; (c), striking N. 60° E. and vertical, forms the northeast and southwest walls; (d), striking N. 20° E. and vertical, discontinuous, is spaced 25 feet and over. The rift is reported as vertical with N. 15° E. course and the grain as horizontal. There is a mass of mica slate on the east wall 100 feet long and 10 feet wide with a foliation striking N. 20° E. and dipping 55° E. It is veined by granite.

The plant comprises one hand and two horse derricks, an air compressor (capacity 110 cubic feet of air per minute), a large rock drill, and three air plug drills.

Transportation is by a siding from the Hardwick and Woodbury Railroad.

FRYATT & CARR PROSPECT.

Fryatt & Carr, of Woodbury, in 1907 were quarrying bowlders and possibly surface sheets a little south of the Webber quarries near the railroad switch on the south side of the track.

BUCK POND QUARRIES AND GRANITES.

Between the southwest end of Buck Pond and the new Webber quarry, roughly 500 feet north of the latter, is an abandoned quarry of biotite granite of dark bluish-gray shade and fine texture (specimen D, XXIX, 69, a) identical with specimens 65, a, and 67, a, of the new Drenan and Webber openings described on pages 102, 103. (See fig. 8.) The sheets, 5 to 8 feet thick, dip gently south. There is an east-west working face 100 feet long and 35 feet high without headings. Two sets of joints strike east and north, respectively.

On the southeast side of the pond, possibly 1,000 feet roughly northwest of the above quarry and on the west side of a granite ridge, is another abandoned opening. The rock (specimen D, XXIX, 70, a) is a biotite granite of light bluish-gray shade but of medium texture, with feldspar to 0.3 inch. It is more bluish than any of the granites of Robeson Mountain. Its texture is slightly coarser than that of the old opening of the Webber quarry (specimen 68, a), and also than the granites on the other side of the pond.

CHASE QUARRIES.

The Chase quarries are on the first high bluff northwest of Robeson Mountain, over 500 feet northwest of Buck Pond and 200 feet above it. (See fig. 8.) They have been idle for several years. The stone is a biotite granite of light bluish-gray shade and medium inclining to fine texture, identical with specimen 68, a, of the Webber main quarry described on page 103. There is a working face on the west 150 feet long and 40 feet high. The sheets, up to 8 feet thick, dip

gently northeast. Pegmatite dikes, 2 inches thick, cross the granite beyond the face with 30° W. dip.

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NICHOLS LEDGE CARTER QUARRY.

The Nichols Ledge Carter quarry is at the northeast foot of Nichols Ledge in the east corner of the town of Woodbury. It is near the A. Dutton house, now occupied by A. D. Kimball. (See fig. 8.) Operator, J. H. McLeod, Hardwick, Vt. It was not worked in 1907.

The granite (specimen D, XXIX, 61, b) is a biotite granite of light inclining to medium bluish-gray shade and of fine to very fine texture, with feldspars up to 0.2 inch and mica to 0.1 inch, also with larger porphyritic clear feldspars formed about the other minerals. It is finer textured than the stone of the new Drenan and Webber openings (pp. 102, 103) and of lighter shade. Its constituents, in descending order of abundance, are clear, colorless potash feldspar (orthoclase and microcline); clear quartz with apatite needles and some cavities in sheets; bluish to milk-white soda-lime feldspar (oligoclase to oligoclase-andesine), but little kaolinized; olive-colored biotite (black mica) and a little muscovite or bleached biotite. Some of the feldspar is minutely intergrown with quartz. Accessory: Titanite, apatite. Secondary: Kaolin, epidote, calcite. It does not effervesce with cold dilute muriatic acid.

The sheets are up to 2 feet thick. There are some biotite knots. A similar granite is reported as once quarried by L. C. Fisher on the north side of Nichols Ledge.

WINDHAM COUNTY.

DUMMERSTON.

GENERAL STATEMENT.

The Dummerston granite area lies 5 and 6 miles north-northwest of Brattleboro and is shown on the state geologic map of 1861 as surrounded by "calciferous mica schist," with a belt of "clay slate" east of it along the Connecticut. The quarries and prospects are in the southwest part of the town on the sides of Black Mountain, and also half a mile south-southwest of it. Black Mountain, as shown on the United States Geological Survey reconnaissance topographic map (Brattleboro sheet), is on the east side of West River, 4 miles west of Connecticut River. This is a roundish granite mass, probably of

south flow structure with its aligned discoid nodules of muscovite has been described on page 25, and the details of the contact of granite and schist given on page 20, and shown in figures 3 and 4. Neither of the quarries has as yet removed all the thin surface sheets, although they have furnished material for several very large buildings.

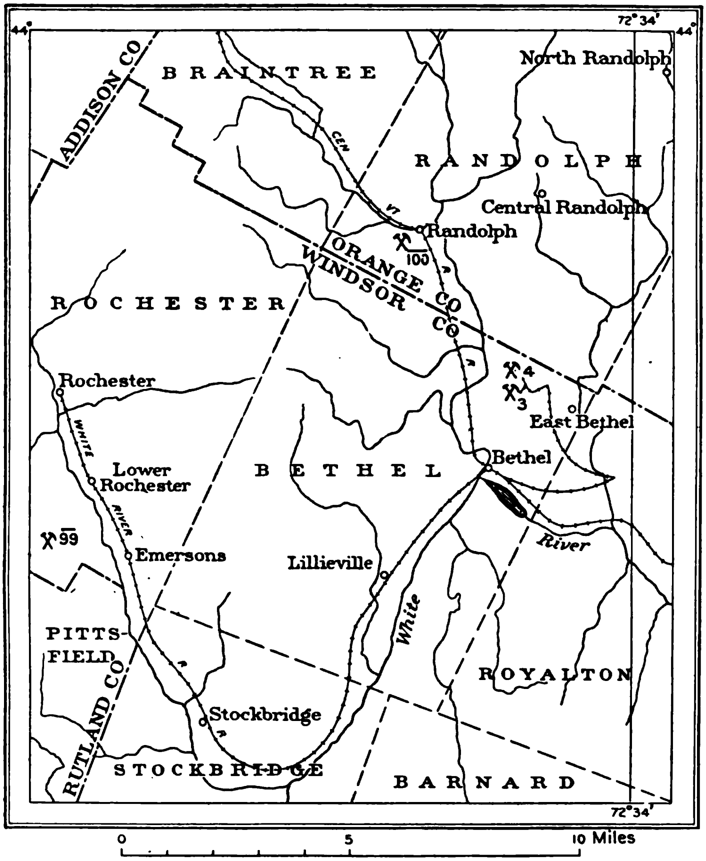


FIGURE 24.—Map of Bethel, Randolph, and Rochester, from Beers's Atlas. No. 3, Woodbury Granite Company's quarry; No. 4, Ellis quarry; No. 99, Liberty Hill quarry; No. 100, Beedle's prospect.

"BETHEL GRANITE."

The granite known under the commercial name "Bethel white granite," which has been copyrighted, and the granite consequently called by another firm "Hardwick white granite," from the location of its main office, are one and the same. The two quarries, but a few feet apart, are excavations in granite of one mass of contemporaneous origin and of identical composition and texture. The following description is based on specimens, rough and polished, and thin sections from both quarries.

The granite of Bethel (specimens D, XXIX, 3, n, p, and 4, a, b), "Bethel white" or "Hardwick white," is a quartz monzonite of slightly bluish milk-white color, with grayish spots up to 0.3 inch, and of coarse inclining to medium texture, with feldspars up to 0.4 and 0.5 inch and mica to 0.3 inch. Its constituents, in descending order of abundance, are: Clear, colorless, rarely bluish quartz, with hairlike crystals of rutile, and with fluidal and other cavities in sheets, with rift cracks parallel thereto; bluish milk-white soda-lime feldspar (oligoclase) slightly kaolinized and micacized; clear potash feldspar (orthoclase, slightly kaolinized, with very little microcline); muscovite (white mica); and very little biotite (black mica). The accessory minerals are apatite, titanite, zircon, and rutile. No magnetite or pyrite was detected. The secondary minerals are kaolin, a white mica, epidote, zoisite in some abundance, and very little calcite.

The stone does not effervesce with cold dilute muriatic acid. W. T. Schaller, chemist, of the United States Geological Survey, finds that it contains 0.07 per cent of CaO (lime) soluble in dilute (10 per cent) acetic acid, which indicates a content of 0.125 per cent of CaCO (lime carbonate), which is very slight.

A chemical analysis made for the E. B. Ellis Granite Company by Charles F. McKenna, of New York, in 1903, is given here for reference.

Analysis of "Bethel granite," by Charles F. McKenna.

SiO_2 (silica)	77.52
Al_2O_3 (alumina)	16.78
FeO (iron oxide)	.84
MgO (magnesia)	.32
CaO (lime)	2.56
Na_2O (soda)	1.21
K_2O (potash)	.62
Loss on ignition	.33
	100.18

Three compression tests (No. 13261) made at the United States Arsenal at Watertown, Mass., yielded these results (direction of rift in blocks not stated):

Compressive strength of white granite of Bethel.

	Pounds per square inch.
First crack, 287,000 pounds; ultimate strength	33,120
First crack, 301,000 pounds; ultimate strength	34,350
First crack, 272,000 pounds; ultimate strength	31,990
Average	33,153

The stone is regarded as relatively hard by workmen. Its grade of whiteness is shown by these comparisons: The "white" of North

Jay, Me., is, technically, *very light gray*. The "white" of West Dummerston is a trifle lighter, that of Randolph (p. —) lighter yet, and that of Bethel still lighter, strictly white *mottled with gray*. Its white is more blue than ordinary Vermont white marble, but is closely allied to its blue variety, but not its bluish gray. Owing probably to the abundance of its soda-lime feldspar, its hammered face is considerably whiter than its rough face and the hammering also diminishes the prominence of the gray micaceous spots. It takes a high polish, but the effect is to make the mica spots more conspicuous than they are even on the rough face. The polished specimens handled by the writer do not show any pyrite or magnetite. Plate V, *A*, representing a carved eagle, shows how the whiteness of the stone has overcome the effect of the coarseness of its texture. Although this granite is remarkably free from iron, its recent use in large edifices shows that extreme care should be exercised in handling it to prevent its absorbing rusty water or other discoloring liquids.

Leonard P. Kinnicutt, of the Worcester Polytechnic Institute, in December, 1908, made the following determinations of absorption in Bethel and other granites, by W. F. Hillebrand's method, for Norcross Brothers Company, of Worcester, Mass.

Water absorbed by 100 pounds of various granites.

	Pound.
Bethel granite	0.470
"New Westerly," Milford, N. H	.420
Hallowell	.405
Concord	.371
Westerly	.340
Milford, Mass	.340
Barre	.294

ELLIS QUARRY.

The Ellis quarry is on the east side of Christian Hill, about 2 miles north of Bethel village in Bethel township. (See fig. 24.) Operator, E. B. Ellis Granite Company, Northfield, Vt.

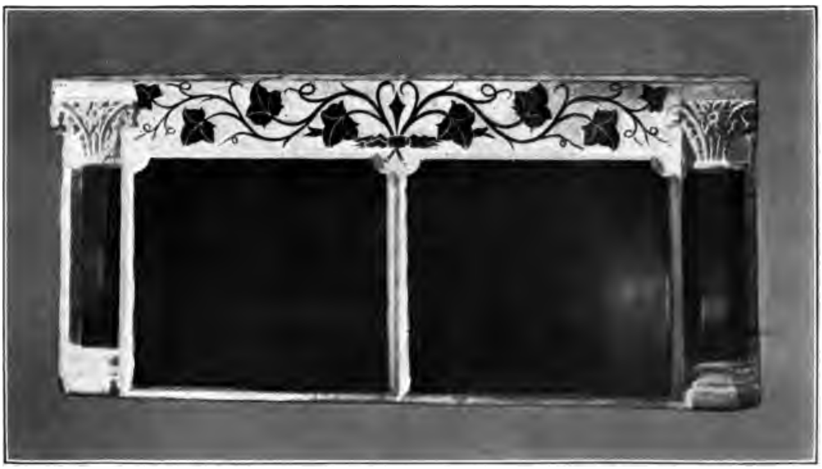
The granite has been described above.

The quarry, permanently opened in 1902, but in a small way many years earlier and abandoned, is estimated as being about 1,000 feet long north-south, and for the southern three-fifths of its length 150 feet wide, but for the remainder 400 feet wide. Its depth is from 5 to 40 feet, averaging about 15 feet. Its western edge is about 80 feet higher than its eastern.

The sheets, from 6 inches to 12 feet thick, but mostly 1 to 2 feet, strike N. 10° W. and on the west side of the north end dip 30° E., but on the east side 15° E. For some not apparent reason the sheets thicken more rapidly at the east side and south end than in any other part of this or the adjoining quarry. Joint, grain, and flow courses

A. CARVED EAGLE OF COARSE WHITE QUARTZ MONZONITE FROM BETHEL OVER ENTRANCE TO AMERICAN BANK NOTE COMPANY'S BUILDING, NEW YORK.

Spread of wings, 32 inches; height from base of medallion to top of head, 7 feet 8 inches; depth of carving, 18 inches. The whiteness of the cut rock has counteracted the effect of its coarseness.



B. MONUMENT OF MOUNT ASCUTNEY DARK-GREEN HORNBLENDE-AUGITE GRANITE (SYENITE).

Showing contrast between polished (black) and hammered (white) surfaces. Size about 5 feet 8 inches by 2 feet 6 inches.

are shown in figure 25. Joint set (A) is vertical, forms a heading at north end, recurs at two intervals of 80 feet; (B) is diagonal to the quarry and vertical, one only, about the middle of the side, but discontinuous. Compressive strain affects east-west channels more than north-south ones. Flow structure marked at the east side and south end, consists of micaceous (muscovite) streaks, up to 0.5 inch wide, and sheets of discoid nodules of muscovite, also of a branching mass, 12 inches thick, largely mica, and is vertical with north course. (For details see p. 25 and Pl. II, *A*.) The rift is reported as horizontal and the grain as vertical, with N. 17° E. course thus intersecting the flow structure at an acute angle. A few pegmatite dikes, up to 5 inches thick, have an east-west course. A quartz vein up to 1.5 inches wide strikes N. 80° W. and dips 65° S. 70° W. Some minute muscovite and quartz veins strike N. 30° to 35° W. and dip 60° S. 58° W. There is one light-gray knot, 10 by 8 by 2 inches; also an inclusion, 21 by 12 by 5 inches, of fine-grained syenite gneiss consisting of orthoclase, biotite, epidote, and a little oligoclase with titanite and leucoxene, but with little or no quartz. There is no rusty stain on sheet surfaces. The relations of the coarse white granite to the fine, light-buff gray, and the contact of the latter with the schist have been described on page 20 and shown in figures 3 and 4.

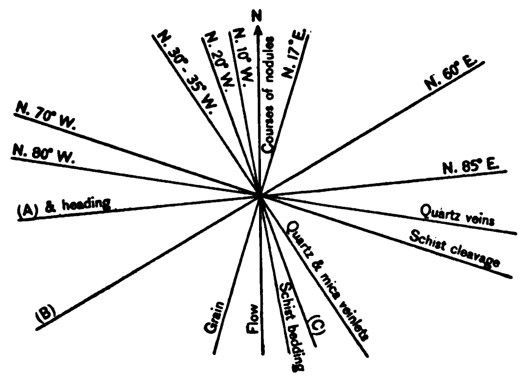


FIGURE 25.—Structure at Ellis and Woodbury granite companies' quarries, Bethel.

The plant at the quarry comprises ten derricks of 15 to 30 tons capacity, nine hoisting engines, an air compressor (capacity 750 cubic feet of air per minute), eleven large air rock drills, twenty-eight air plug drills, and four steam pumps.

The cutting plant at Northfield, Vt., comprises a 25-ton derrick and engine, a 50-ton derrick and electric motor, two 20-ton and one 10-ton overhead crane, three air compressors (capacity, two of 800 and one of 300 cubic feet of air per minute), six air plug drills, one hundred and fifty air hand tools, eleven surfacers, two lathes for stones 25 by 3 by 2 feet; one Dietrich Harvey Company turning and fluting machine for columns 40 by 7 feet. The cutting plant is run by five electric engines, two of 100, two of 75, one of 35, and one of 15 horsepower. Electricity is brought 14 miles from Mad River.

Transportation is effected by siding, as shown in figure 24. Blocks destined for cutting are brought 5 miles to Bethel and thence 28 miles to the cutting shed at Northfield.

The product is used for buildings, monuments, and statuary. Specimens are the Union Station, with six monolithic statues 17 feet high, also with four eagles 8 feet high with spreading wings nearly 12 feet from tip to tip, and the first and second stories of the National Museum, Washington, D. C.; all the superstructure above water table in the State Library and Supreme Court Building, Hartford, Conn.; Hopper Monument, Woodlawn Cemetery, New York; Miller mausoleum, Poughkeepsie, N. Y.; Congdon residence, Duluth, Minn.

WOODBURY COMPANY'S QUARRY.

The Woodbury Company's quarry is 50 feet north of the Ellis quarry, on the east side and top of Christian Hill, about 2 miles north of Bethel village, in Bethel township. (See fig. 24.) Operator, Woodbury Granite Company, Hardwick, Vt.

The granite has been described on page 111.

The quarry, opened in 1902, is estimated as measuring about 500 feet north-south by 200 feet across and from 5 to 30 feet in depth.

The sheets, from 6 inches to 8 feet thick, are normal, dipping about 15° E. At a recent small opening, about 300 feet north of the main one and on the east side of the highest part of the hill, the sheets dip 45° E. There are two sets of joints (courses in fig. 25): (a), vertical, forms a 10-foot heading on the south wall between this and the Ellis quarry; (C), also vertical, is discontinuous and spaced 10 to 40 feet. An east-west compressive strain is reported by the foreman. The rift is reported as dipping less than 15° E., and the grain as vertical, with nearly east-west course. Very few of the discoid micaceous nodules referred to (p. 113) occur. About 40 feet of fine buff-gray granite with schist farther east correspond to the same rocks on the west side of Ellis quarry. There is no rusty stain on sheet surfaces except near the heading.

The plant at the quarry comprises five derricks (one with 90-foot mast, the rest with 50 to 70 foot masts), a Blondin carrier, two air compressors (capacity 556 and 450 cubic feet of air per minute), four large rock air drills, 12 air plug drills, and two steam pumps.

The cutting plant at the firm's shed one-half mile south of Bethel village comprises one derrick, a 30-ton, a 20-ton and a 10-ton overhead electric crane, two air compressors (capacity 1,200 and 260 cubic feet of air per minute), four air plug drills, 52 air hand tools, three surfacers, a polisher, and a 300-horsepower dynamo. Electricity is brought 5 miles from White River for this plant and sent 4 miles farther to the quarry.

Transportation is by cart, 4 miles to the cutting shed near Bethel, which is on a siding.

The product is used for buildings. Examples are the new capitol of Wisconsin at Madison; American Bank Note Building, New York (Pl. V, *A*, represents a carving of this granite over the entrance to this building); Importers and Traders' National Bank, New York; Harry Payne Whitney residence, New York; Mary Ann Brown Memorial Library, Providence R. I.; grammar and high school buildings, Hartford, Conn.; entrance to Majestic Building, Detroit, Mich.

ROCHESTER.

LIBERTY HILL QUARRY.

The Liberty Hill quarry is 3 miles south of Rochester village (the west terminal of the White River Valley Railroad) and on the Rochester-Pittsfield town line. The outcrop extends into the town of Pittsfield, in Rutland County. (See fig. 24.) Operator, Liberty Hill Granite Corporation, Rochester, Vt.

The granite (specimens D, XXIX, 99, a, b), "coarse white granite," is a quartz monzonite of slightly greenish-white color with conspicuous brilliant muscovite spots up to 0.5 inch across and of coarse texture, with feldspars up to 0.5 inch. These mica spots being collections of mica scales, have a peculiar sheen. As they are not over 0.04 inch thick and lie with their flat sides roughly parallel, the rock has a somewhat gneissoid texture. Its constituents, in descending order of abundance, are: Milk-white to slightly greenish soda-lime feldspar (albite to oligoclase-albite), somewhat kaolinized and with thickly disseminated white mica scales to 0.15 millimeter long and not a few plates of calcite; clear colorless to pale bluish quartz rarely with hairlike crystals of rutile, and with fluidal and other cavities in two rectangular sets of sheets, one set with many more cavities than the other; orthoclase may be present in small amount, but was not detected. There is no microcline; muscovite (white mica) in large flakes and aggregates.

An estimate of the mineral percentages by the Rosiwal method yields these results with a mesh of 0.5 inch, total linear length of 35.5 inches, and on face at right angles to gneissoid structure:

Estimated mineral percentages in white granite of Rochester.

Feldspar	62.1
Quartz	29.6
Muscovite	8.3
	100.0

The average diameter of all the particles obtained from the same measurements proves to be 0.34 inch; that of feldspar, 0.194; quartz, 0.106; and mica, 0.538 inch.

The stone effervesces with cold dilute muriatic acid. W. T. Schaller, chemist of the United States Geological Survey, finds that it contains 1.38 per cent of CaO (lime) soluble in warm dilute (10 per cent) acetic acid, which indicates a content of 2.46 per cent of $CaCO_3$ (lime carbonate, calcite), the presence of which mineral is also shown in thin section.

This is a building granite of very light pale greenish-gray color, with striking contrasts produced by large mica spots, the brilliancy of which on the fresh rift face is almost metallic. Whether its somewhat gneissoid texture and its content of nearly 2½ per cent of lime carbonate are serious obstacles to its use for building can only be determined by compression tests and by continued exposure to the weather.

The quarry, opened after the completion of the author's manuscript, was not visited.

In 1909 the corporation was filling a contract for the base course for the new gymnasium for Dartmouth College at Hanover, N. H.

Although the outcrop is 3 miles from Rochester station, its distance from the nearest point on the railroad is only about a mile and a siding is reported as having been constructed.

WINDSOR.

TOPOGRAPHY AND GENERAL GEOLOGY.

The state map of 1861 shows a granite area in the southern parts of Windsor and West Windsor and the northern part of Weathersfield. The geology of this area has been made known by R. A. Daly in an elaborate report already referred to.[a] His map (Pl. VII) shows that Mount Ascutney, which lies about 5 miles southwest of Windsor village and rises 2,800 feet above the Connecticut and 3,100 feet above sea level, consists mainly of a mass, about 2½ miles square, of greenish hornblende-augite granite (syenite) intrusive in schists which crop out along its base. But adjoining this syenite on the west is an area of still older gneisses, which are intruded by a mass of gabbro and diorite about 2 by 1½ miles in area. That this intrusion is older than that of the syenite is shown by the fact that dikes of the syenite penetrate it. The syenite of Mount Ascutney was itself in turn intruded by a very irregular mass of biotite granite characterized by abundant dark segregations (knots) and covering about a square mile. This granite was formerly quarried and monuments of it can be seen in the Windsor cemetery.

"WINDSOR GRANITE."

"Windsor granite" (syenite, nordmarkite phase of Daly) is a hornblende-augite granite which when first quarried is of dark bluish-gray color, but after very brief exposure becomes dark olive

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[a] Bull. U. S. Geol. Survey No. 209, 1903.

green. Its texture is medium to coarse, with feldspars up to 0.3 and 0.5 inch and black silicates to 0.2 inch. Its constituents, in descending order of abundance, as made out from the study of four thin sections, two from each quarry, are: (1) Dark olive-green potash feldspar (orthoclase) minutely or obscurely intergrown with soda-lime feldspar (certainly oligoclase in two of the slides), with cleavage planes stained with limonite; (2) dark smoky quartz with cavities (apparently without vacuoles, some of them of quartz crystal form) in streaks and sheets and crossed by intersecting cracks filled with limonite stain; (3) green hornblende; (4) augite, associated with or inclosed by (3); (5) biotite in very small quantity, in three slides none. The accessory minerals observed are titanite, magnetite or ilmenite, zircon, apatite, and allanite. The secondary are limonite and white mica in the feldspar.

The cause of the change in the color of the feldspar and thus of the granite upon exposure has already been referred to (p. 12). It does not effervesce with cold dilute muriatic acid. It is very hard and has a metallic ring under the hammer. It is brilliant in the rough from the cleavage faces of the large feldspars. Their shade is so dark that the black silicates only appear on close inspection. Owing to its extremely small content of mica it takes a very high polish, quite as high as that of the granite of Quincy. Its polished face is much darker than its rough face, but the hammered or cut face, being of medium greenish gray, is much lighter than either, so that lettering or carving stands out boldly on the polished face. (See Pl. V, *B*.) It is best adapted for internal decorative use.

MOWER QUARRY.

The Mower quarry is on the west side of Mount Ascutney nearly 1¼ miles south of Brownsville and 580 feet above it, in West Windsor. Operator, Ascutney Mountain Granite Company, Windsor, Vt.

The granite, already described, has received the trade name of "bronze vein green."

The opening, made in 1906, is about 50 feet square, and averages 10 feet in depth.

The sheets, 10 feet thick, are horizontal or dip 5° W. There are three sets of joints: (a) Striking N. 85° E. and vertical, is spaced 2 to 18 feet; (b) striking N. 30° E., dips 75° S. 60° W., one forming the east wall; (c) striking N. 55° W., dips 65° N. 35° E., one forming the south wall. The rift is reported as vertical with N. 85° E. course and the grain as horizontal. There is a black bronzy streak dipping 45° E., possibly of the black silicate, and showing the direction of flow. Light rusty brown and cream-colored discoloration is 0.5 inch thick on the joint faces. In thin section some of the limonite stain of this rim proceeds clearly from magnetite (or ilmenite), augite, and allanite particles.

The plant at the quarry comprises three derricks (one of 20 tons and one hand), and two hoisting engines. At the cutting shed in Windsor it includes two hand derricks, an overhead 8-ton crane, a 50-horsepower engine, an air compressor (capacity 125 cubic feet of air per minute), a cutting and a polishing lathe for stones 5 feet 6 inches by 1 foot 6 inches, and a set of twelve chilled shot saws for blocks 12 feet long.

Transportation is by gravity track 600 feet long and 30 per cent grade from the quarry to road and thence by cartage 8½ miles to Windsor.

The product is used mainly for dies, wainscoting, and indoor columns. Specimens: The two monolithic sarcophagi in the McKinley mausoleum at Canton, Ohio. When finished these measured 8 feet 10 inches by 4 feet 4 inches by 2 feet 6¾ inches. The covers measured 9 feet 4½ inches by 4 feet 8¾ inches by 1 foot 3¾ inches. The polishing of these stones was done by another firm. The monument (Pl. V, *B*) shows the contrast between cut and polished faces, somewhat exaggerated in photographing, the black representing what is a dark olive green and the white what is a medium greenish gray.

NORCROSS QUARRY.

The Norcross quarry is on the north side of Mount Ascutney on the 1,350-foot level, about 950 feet above Windsor village, and a little over a mile east-southeast of Brownsville, in Windsor. Operator, Windsor Green Granite Company, Worcester, Mass. This quarry is only operated occasionally.

The granite has been described on pages 116, 117.

The quarry is about 200 feet east to west by 40 feet across and has a working face 60 feet high on the south, with a rugged cliff above it, making a total face of 80 to 90 feet above the quarry bottom and road.

The sheets, from 2 to 10 feet thick, are horizontal or dip 10° N. There are two sets of joints: (a), striking N. 75° to 80° E., vertical, is spaced 2 to 10 feet; (b), striking N. 5° W., vertical, is spaced 5 to 30 feet, with a 10-foot wide heading through the center of the quarry. The splitting has been done in the direction of (a), which is the rift direction at the Mower quarry and presumably here also. There are many dark streaks. A 4-foot dike crosses the quarry parallel to and within heading (b). This appears to be also a hornblende-biotite granite. It is of medium greenish-gray color and of medium inclining to fine texture with feldspars mostly under 0.2 inch, rarely 0.4 inch, and black silicates mostly under 0.1 inch. Its constituents, in descending order of abundance, are: Greenish medium-gray potash feldspar with obscurely intergrown soda-lime feldspar, kaolinized; smoky quartz, more of it than in the adjacent granite; finely striated soda-lime feldspar (oligoclase-albite); hornblende; a little biotite.

Accessory: Magnetite or ilmenite, titanite, and allanite. Secondary Kaolin.

The sheet surfaces, chiefly owing to the kaolinization of the feldspar, are discolored to a medium slightly greenish gray and the joint faces are similarly discolored, but with a limonitic border. The discoloration is from 1 to 1.5 inches thick.

The plant consists of three derricks, a hoisting engine and steam drill.

Transportation is by cartage to rail at Windsor.

The product has been used for monumental and decorative purposes. Specimens: Sixteen polished columns (24 feet 9½ inches by 3 feet 7 inches) in Columbia University Library, New York; monument to General Gómez in Cuba; a die in the Bennington monument; 34 large columns in the Bank of Montreal; columns and die of W. C. T. U. fountain, Orange, Mass.

CHARACTERISTICS AND ADAPTATIONS OF VERMONT GRANITES.

Although differing widely in their characteristics Vermont granites do not include a great variety of colors or texture. They are gray, whitish, and pinkish constructional granites of medium to coarse texture, gray monumental granites of fine to medium texture, and one dark-green polish and inscriptional granite of medium to coarse texture. Those which have thus far proved of principal economic importance are the gray monumental granites and the whitish constructional granite. The adaptability of "Barre granite" to sculpture is shown in the statue (Pl. III, *A*); that of the "Woodbury Bashaw" in the bas-relief (Pl. IV, *A*), and that of the coarse granite of Bethel in the eagle (Pl. V, *A*). The suitableness of the green granite of Windsor for indoor decorative use and for inscriptions is shown in the polished and cut monument (Pl. V, *B*).

Among the notable buildings and monuments made of Vermont granite are the capitols of Vermont, Pennsylvania, and Wisconsin, the State Library and Supreme Court Building at Hartford, Conn., the Union Station and the first and second stories of the National Museum at Washington, D. C., the Cook County court-house at Chicago, Ill., the prison-ship martyrs' monument in Brooklyn, N. Y., and the sarcophagi for President and Mrs. McKinley at Canton, Ohio.

CLASSIFICATION OF VERMONT GRANITES.

In the following table all the granites described in this bulletin, except that of the Parmenter quarry, near Beebe Plain, are grouped by their economic uses. The trade name, the scientific name, the real general color and shade (without reference to spots or spangles), and the texture of each stone are given in separate columns, and page references to the descriptions of the stone and quarries are also added.

Classification of Vermont granites.

Economic group.	Locality.	Trade name.	General color and shade.	Texture.	Petrographic name.	Described on page—
Constructional	Derby		Light bluish gray	Medium-fine	Quartz monzonite with both micas.	45
	Calais. (See under Monumental.)					
	Woodbury (Robeson Mountain).	Woodbury gray (Fletcher).	Light gray	Medium	Biotite granite	96
	do	Woodbury gray (Woodbury Granite Co.).	Medium gray (contrasts medium).	do	do	98
	Woodbury (prospect)		Very light, slightly buff gray	do	do	103
	Dummerston (Black Mountain).	White West Dummerston.	Very light gray	do	Quartz monzonite	106
	Dummerston (Bailey)		Light gray	Medium-fine	do	108
	Bethel (Ellis)	Bethel white	Slightly bluish milk-white, mottled.	Coarse-medium	do	112
	Bethel (Woodbury Co.)	Hardwick white	do	do	do	114
	Rochester (Liberty Hill)		Slightly greenish white, large micas.	Coarse	do	115
	Randolph (prospect)	Fine white	Extremely light gray	Fine	do	43
	Newark (prospect)	Newark pink	Light pinkish gray	Coarse	Biotite granite	33
	Barre (Bond & Whitcomb)	Coarse light Barre	Light gray	Medium	do	72
	Barre (Wheaton)	White Barre	Very light gray	do	do	87
Monumental	Hardwick (Buffalo Hill)	Dark blue Hardwick	Dark gray	Medium	Quartz monzonite	27
	Kirby (Grout quarry)		Light to medium, slightly bluish gray.	Medium-fine	Biotite granite	29
	Kirby (Kearney Hill)		Light gray	Medium-coarse	Quartz monzonite	31
	Kirby (Burke quarry)		Light to medium gray	Medium-fine	do	32
	Ryegate (Gibson, etc.)		do	Medium	do	36, 37
	Ryegate (Rosa quarry)	Fine gray	Medium gray	Fine, inclining to medium.	Biotite granite	38
	do	Coarse gray	Medium bluish gray	Medium	do	39
	Ryegate (Frazer quarry)		Light-medium gray (contrasts marked).	Medium-coarse	Quartz monzonite	40
	Groton	Vermont blue	Medium quite bluish gray	Medium-fine	do	41
	Topsham (Ricker)		Medium bluish gray	Medium	do	42
	Barre (Jones, Wetmore & Morse).	Light Barre	Light-medium slightly bluish gray.	Fine, inclining to medium.	Biotite granite	65, 68
	Barre	Medium Barre	Medium bluish gray	Fine	do	71, 72
	Barre (Bond & Whitcomb, new quarry).	do	Medium gray	do	do	73
	Barre (Smith upper quarry).	Medium Barre	Light-medium slightly bluish gray.	Fine-medium	do	69

Monumental	Barre	Dark Barre	Dark-medium bluish gray	Fine or fine to medium	do	57, 58 et seq.
	Barre (Milne & Wylie and Jones dark quarries).	do	Dark bluish gray	Fine-medium	Biotite granite, but quite a little plagioclase, and cuts light.	59, 85
	Barre (Marr & Gordon, knot)	Very dark	Very dark bluish gray	do	Biotite granite	62
	Cabot (Lambert)	Dark	Dark bluish gray	Fine	Quartz monzonite	90
	Calais (Patch quarry)	Medium gray	Medium slightly bluish gray	Medium	Biotite granite	91
	Calais (Lake Shore quarry)		Light-medium gray	Fine	do	92
	Woodbury (Drenan & Webber, new quarries).	Woodbury fine dark	Dark bluish gray	do	do	102, 103
	Woodbury (Robeson Mountain).	Woodbury Bashaw	Medium gray (contrasts weak).	Fine-medium	do	98
	Woodbury (Webber (old) & Chase).		Light bluish gray	Medium-fine	do	103, 104
	Woodbury (Leach)		Dark bluish gray	do	do	105
	Woodbury (Carter)		Light-medium bluish gray	Very fine to fine	do	105
	Dummerston (Black Mountain).	Dark blue	do	Fine-medium	Quartz monzonite	106
	Dummerston (Bailey)		Medium bluish gray	Very fine	do	108
Polish and inscriptional (indoor)	Windsor	Green Ascutney, bronze vein green.	Dark olive green	Medium-coarse	Hornblende-augite	116

COMMERCIAL VALUES OF VERMONT GRANITES.

It is not within the province of this paper to give price lists, but as the current commercial value of a stone is a measure of its quality and an indication of the possibilities of its use a few prices of Vermont granites for 1907 are added. These prices are all for the rough stone and f. o. b.

The whitish quartz monzonite of Bethel is sold for constructional use at $1 per cubic foot, ordinary sizes, and in selected blocks for monumental use at $2. The very light gray quartz monzonite of Dummerston is 50 cents per cubic foot, random stock; and the light medium bluish gray from the same quarry for monumental use is 75 cents per cubic foot, ordinary sizes. The "Woodbury gray" constructional granite is 50 cents and the monumental granite from Woodbury ("Bashaw") 75 cents. Monumental granites of Barre range as follows for blocks of 80 cubic feet and under: "Light," $1.15; "medium," $1.25; "dark medium," $1.40; "dark," $1.50. Barre constructional, "coarse light" (Bond & Whitcomb), sells at 25 cents, dimension stone. The gray monumental granites of South Ryegate are 45 cents, ordinary sizes. The green polish and inscriptional syenite of Windsor sells for $1.50. In 1909 the very light of Beebe Plain was selling at 40 cents per cubic foot, f. o. b. cars at North Derby.

Summarizing, the constructional granites range from 25 cents to $1 per cubic foot; the monumental from 75 cents to $2. The polish and inscriptional are $1.50 per cubic foot.

STATISTICS OF GRANITE PRODUCTION IN VERMONT.

By Altha T. Coons.

The first statistical work on Vermont granite by the United States Geological Survey was done in connection with the Tenth Census, and gave the output of granite for the year ending May 31, 1880. There were 12 quarries reporting for that year, and the total output was 187,140 cubic feet, valued at $59,675. The next figures available for Vermont granite were for 1886, when the output, chiefly monumental stone from the Barre quarries, was reported as 240,000 cubic feet, valued at $180,000. The year 1887 represented a gain of 25 per cent over the output for 1886, and was 300,000 cubic feet, valued at $225,000. The Eleventh Census gave the output of granite for the census year as valued at $581,870, and the Twelfth Census gave an output for the year 1902, the product of 68 quarries, valued at $1,570,423, an increase of 169.9 per cent in thirteen years, or of 2,531.6 per cent for the twenty-three years, represented by different census figures. From the time of the Eleventh Census, the statistics of Vermont granite production have been regularly collected, the

entire output increasing steadily, although not regularly, as the years were more or less differently affected by labor troubles, chiefly in the building trades. The stone of the State was at first chiefly used for monumental work, but recently a large quantity has been used in building, a small quantity made into paving blocks, and equally small quantities were sold as crushed stone for road making, ballast, curbing, etc.

The following table shows the value of the granite produced in Vermont, as compiled by the United States Geological Survey from 1880 to 1907:

Production of granite in Vermont from 1880 to 1907.

Year.	Rough.		Dressed.		Paving.		Other purposes.[a]	Total value.
	Building.	Monumental.	Building.	Monumental.	Number of blocks.	Value.		
1880								$59,675
1886								180,000
1887								225,000
1888								279,000
1889								581,870
1890								610,963
1891								700,000
1892								675,000
1893								778,459
1894	$861,245					$32,711		893,956
1895	977,016					30,702		1,007,718
1896	864,526					30,990		895,516
1897	$430,121		$283,167	$341,034		16,770	$3,208	1,074,300
1898	531,634		113,922	416,878		4,446	17,338	1,084,218
1899	563,475		125,775	509,358		3,500	10,859	1,212,967
1900	526,370		49,763	527,053		225	10,377	1,113,788
1901	$208,825	$534,755	16,343	354,563		16,304	115,038	1,245;828
1902	28,845	756,007	289,567	453,187		2,855	39,962	1,570,423
1903	103,353	828,508	346,293	481,346		28,839	21,840	1,810,179
1904	83,148	797,830	912,801	615,057	382,758	14,745	24,398	2,447,979
1905	188,391	778,681	1,093,688	471,093	413,898	16,628	23,369	2,571,850
1906	47,154	993,220	1,422,862	451,222	282,930	9,557	10,810	2,934,825
1907	29,764	1,122,063	1,009,353	515,859	171,000	5,330	11,520	2,693,889

[a] Includes stone for roads, curbing, ballast, etc.

The figures as given in the table show the values obtained free on board by the quarrymen for the stone quarried by them, and do not represent the stone sold by manufacturers. When quarrymen dress their own stone, the value of the dressed stone is given as representing the value of the material to the quarrymen. For the years 1906 and 1907, it has been possible to tabulate the quantity of stone sold for building and for monumental work. This is of interest as showing the proportion of stone sold for building and for monumental purposes, and also showing practically the number of cubic feet of granite sold in Vermont for these years, the quantity of stone for other purposes being almost negligible.

The following table shows the production of granite in Vermont in 1906 and 1907 by counties and uses, and also the total value for the United States for the same interval:

Production of granite in Vermont in 1906 and 1907, by counties.

1906.

County.	Number of firms reporting.	Building. Rough. Quantity (cubic feet).	Building. Rough. Value.	Building. Dressed. Quantity (cubic feet).	Building. Dressed. Value.	Monumental. Rough. Quantity (cubic feet).	Monumental. Rough. Value.	Monumental. Dressed. Quantity (cubic feet).	Monumental. Dressed. Value.	Paving. Quantity (number of blocks).	Paving. Value.	Other purposes.	Total.
Washington and Orange	32	66,762	$42,138	234,946	$771,169	1,006,436	$879,745	110,277	$428,035	112,930	$3,647	9,688	$2,134,422
Windsor	4	....	....	191,793	651,693	2,200	3,200	14,534	22,447	....	....	....	677,340
Caledonia, Essex, and Orleans	14	2,000	1,000	....	....	206,947	110,275	1,850	740	....	....	700	112,715
Windham	3	11,300	4,016	....	....	....	....	....	....	170,000	5,910	422	10,348
Total, Vermont	53	80,062	47,154	426,739	1,422,862	1,215,583	993,220	126,661	451,222	282,930	9,557	10,810	2,934,825
Total, United States	....	....	1,770,918	....	6,659,104	....	2,293,144	....	1,822,521	....	1,459,915	4,557,204	18,562,806

1907.

County.	Number of firms reporting.	Building. Rough. Quantity (cubic feet).	Building. Rough. Value.	Building. Dressed. Quantity (cubic feet).	Building. Dressed. Value.	Monumental. Rough. Quantity (cubic feet).	Monumental. Rough. Value.	Monumental. Dressed. Quantity (cubic feet).	Monumental. Dressed. Value.	Paving. Quantity (number of blocks).	Paving. Value.	Other purposes.	Total.
Washington and Orange	39	35,543	$25,239	100,081	$234,583	1,144,263	$1,037,993	136,103	$503,759	5,000	$150	3,645	$1,805,369
Windsor	4	....	....	204,076	774,460	1,847	3,254	3,000	12,000	....	....	....	789,714
Caledonia and Orleans	9	3,300	1,400	....	....	143,427	77,816	....	....	....	....	1,751	80,967
Windham	3	4,450	3,125	325	310	3,371	3,000	40	100	166,000	5,180	6,124	17,839
Total, Vermont	55	43,293	29,764	304,482	1,009,353	1,202,908	1,122,063	139,143	515,859	171,000	5,330	11,520	2,693,889
Total, United States	....	....	1,280,769	....	4,752,593	....	2,239,227	....	2,099,492	....	1,928,308	5,756,997	18,057,386

In 1907 the total value of the granite produced in the United States was $18,057,386, which, compared with the total value for Vermont of $2,693,889, shows that in this year Vermont produced 14.92 per cent of the total value of granite sold in the United States. In 1907 Vermont ranked first in the value of output, followed by Massachusetts and Maine with productions valued at $2,328,777 and $2,162,277, respectively. In 1906 Vermont ranked second in the value of production, the value for this year of $2,934,825 being exceeded by Massachusetts with an output valued at $3,327,416 and followed by Maine with an output of $2,560,021, the total output of granite for Vermont in 1906 being 15.81 per cent of the total of the United States.

The total value of granite sold, rough and dressed, by the quarrymen for building stone in the United States in 1906 was $8,430,022, of which Vermont's share was $1,470,016, or 17.44 per cent of the total. In 1907 the total for the United States was $6,033,362, with Vermont representing $1,039,117, or 17.20 per cent of the total. The total value of granite, including rough and dressed stone as sold by the quarrymen in the United States for monumental work, was, in 1906, $4,115,665, Vermont's production being valued at $1,444,442, or 35.10 per cent. In 1907 this total was $4,338,719, Vermont representing $1,637,922, or 37.75 per cent. The value of the total granite output for Vermont decreased somewhat in 1907 as compared with 1906, or from $2,934,825 in 1906 to $2,693,889 in 1907, a decrease of $240,936. The principal decrease was in the value of the building stone sold, which, including rough and dressed stone, was from a value of $1,470,016 in 1906 to $1,039,117 in 1907, a loss of $430,899. The total monumental stone, however, increased from a value of $1,444,442 in 1906 to $1,637,922 in 1907, a gain of $193,480. The loss in building stone production was due to financial depression affecting general building conditions, especially in large cities.

In 1906, of the 1,849,045 cubic feet of stone sold for building and monumental work, the quantity for building purposes alone was 506,801 cubic feet, or 27.41 per cent of the total, while 1,342,244 cubic feet, or 72.59 per cent of the total was for monumental stone. The value, however, reported for the building stone, rough and dressed, was $1,470,016, or 50.44 per cent of the total, and for the monumental stone $1,444,442, or 49.56 per cent of the total, these percentages being nearly the same, while the quantity of monumental stone was over two and one-half times as much as the quantity sold for building work. This is accounted for from the fact that by far the greater part of the monumental stone was sold to the manufacturers to be dressed, while the producers of building stone dressed their own material. The average price per cubic foot of rough building stone in 1906 was 59

cents; dressed, $3.33. The average price per cubic foot of rough monumental stone in 1906 was 82 cents; dressed $3.56.

In the same manner the total quantity of building and monumental stone for 1907 amounted to 1,689,826 cubic feet; 347,775 cubic feet, or 20.58 per cent being building stone, and 1,342,051 cubic feet, or 79.42 per cent, being monumental stone. The total value of building and monumental stone was $2,677,039, and of this $1,039,117, or 38.82 per cent, was the value for building stone, and $1,637,922, or 61.18 per cent, the value of monumental stone. The average price per cubic foot of rough building stone in 1907 was 69 cents; dressed stone, $3.31; and the average price per cubic foot of rough monumental stone was 93 cents; dressed stone, $3.71.

The total quantity and value of building and monumental stone sold in 1907 decreased 159,219 cubic feet in quantity and $237,419 in value as compared with 1906, or from 1,849,045 cubic feet, valued at $2,914,458, in 1906, to 1,689,826 cubic feet, valued at $2,677,039, in 1907. The decrease was in the quantity and value of building stone, which amounted to 506,801 cubic feet, valued at $1,470,016, in 1906, and 347,775 cubic feet, valued at $1,039,117, in 1907, a decrease of 159,026 cubic feet in quantity and $430,899 in value. This is accounted for by the general depression in the building trade, fewer contracts being given to or taken by the quarrymen on account of the financial depression. In 1906 the output of monumental stone was 1,342,244 cubic feet, valued at $1,444,442, and in 1907 it was 1,342,051 cubic feet, valued at $1,637,922, a decrease of 193 cubic feet in quantity and an increase in value of $193,480.

The largest output is from Washington County, and includes the towns of Barre, Calais, and Woodbury. Windsor County has the next largest production, the output being from Bethel, Chester, and Windsor. The Caledonia County output ranks next and includes Kirby, Groton, Hardwick, and Ryegate. The Windham County output comes from Dummerston. The other localities giving smaller outputs, representing not more than one firm, are in Williamstown, Orange County, and Derby, Orleans County.

METHODS IN THE USE OF EXPLOSIVES.

In Bulletin 313 (pp. 69–72) the methods in the use of explosives prevalent among Maine quarrymen were given, and in Bulletin 354 (pp. 70–72) additional data of the same sort, gathered in the granite quarries of Massachusetts, New Hampshire, and Rhode Island, were published. There is but little to add on this subject from the Vermont quarries.

At Barre, wherever the sheets are imperfectly developed, this method is adopted: A thick rectangular block is obtained by channeling along a vertical rift, and also at two points along the hard way, at

right angles to the rift, the fourth side being that of a joint or heading. An artificial sheet parting is then made by drilling divergent holes 10 feet deep along a horizontal grain. These holes taper from 1½ inches to 1 inch and are filled with but small charges of powder.

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The substance of the paper by Merrill in vol. 10 of the United States Tenth Census, 1888, and by Merrill in the Proceedings of the U. S. National Museum, vol. 6, 1883, has reappeared in more modern form in his other works.

The work of Hirschwald in the above bibliography is of special interest, as its conclusions are based upon the microscopic study of specimens taken from buildings none of them less than fifty years old and a number several centuries old.

GLOSSARY OF SCIENTIFIC AND QUARRY TERMS.

ACCESSORY MINERALS in granite are original constituents of the rock, found only in small, often only in microscopic quantity.

ACIDIC. A term applied to rocks in which silicic acid (silica) or quartz predominates.

ALLANITE. An opaque black mineral (silicate), brown in thin section, one of the primary less common accessory constituents of granite, which contains from 12 to 17 elements, including 6 of the rarer ones. For analyses see Dana, E. S., System of Mineralogy, 6th ed. 1892.

ANTICLINE. A term applied to granite sheets or sedimentary beds that form an arch.

APLITE. Fine-grained granite, usually occurring in dikes and containing little mica and a high percentage of silica.

BASIC. A term applied to rocks in which the iron-magnesia minerals and feldspars with lime and soda predominate, such as diabase or basalts.

BLACK HORSE. Term used by quarrymen in Rhode Island to denote a dark biotite gneiss in contact with the granite.

BLIND SEAMS. Quarrymen's term for incipient joints.

BOWLDER QUARRY. One in which the joints are either so close or so irregular that no very large blocks of stone can be quarried.

CHANNEL. A narrow artificial incision across a mass of rock, which, in the case of a granite sheet, is made either by a series of contiguous drill holes or by blasting a series of holes arranged in zigzag order.

CLEAVAGE, when applied to a mineral, designates a structure consequent upon the geometrical arrangement of its molecules at the time of its crystallization.

CLOSE-JOINTED. A term applied to joints that are very near together.

CRINOID STEM. Part of the calcareous skeleton of a plantlike marine animal related to "starfishes" and "sea urchins," but rooted and provided with an articulated stem, bearing a cup containing the alimentary organs.

CROCUS. A term used in the Milford, N. H., quarries to denote gneiss or any other rock in contact with granite.

CRUSH-BORDER. A microscopic granular structure sometimes characterizing adjacent feldspar particles in granite in consequence of their having been crushed together during or subsequent to their crystallization.

CUT-OFF. Quarrymen's term for the direction along which the granite must be channeled, because it will not split. Same as "hard way."

DENDRITES. Plantlike crystallization of iron or manganese oxides on the surfaces of fissures in any rock or mineral. Frost crystals on window panes are of like character.

DIKE. A mass of granite, diabase, basalt, or other rock which has been erupted through a narrow fissure.

DIMENSION STONE. A term applied to stones that are quarried of required dimensions.

DIP. The inclination from the horizon, given in terms of degrees, of a sheet, joint, heading, dike, or other structural plane in a rock.

DRIFT. Sand and bowlders deposited by the continental glacier.

DRUMLIN. Oval hillock of clay and bowlders formed beneath the ice sheet of the glacial epoch.

EROSION. The wearing away of portions of a rock by such natural agencies as stream or ice action.

EXFOLIATION. The peeling of a rock surface in sheets owing to changes of temperature or other causes.

FAULTING. The slippage of a rock mass or masses along a natural fracture.

FLOW-STRUCTURE. The parallel arrangement of the minerals in granite or other igneous rock in the direction of its flowage during its intrusion.

GEODE. A rock cavity lined with crystals. Geodes in granite are attributed to steam or gas bubbles.

GRAIN in granite is practically the direction in which the stone splits "next easiest," the "rift" being that in which it splits most readily.

GRAPTOLITE. An extinct marine plantlike communal animal organism related to the early stage of certain "jelly fish." They were probably attached to seaweeds.

GROUT. A term applied to the waste material of all sizes obtained in quarrying stone.

GROW-ON. Quarrymen's term to designate the place where the sheet structure dies out, or the place where two sheets appear to grow onto one another.

HARD-WAY. The direction at right angles to both rift and grain in which granite does not split readily. (See Cut-off.)

HEADING. A collection of close joints.

HEADING-SEAM. See Joint.

HEMATITE. An oxide of iron (Fe_2O_3) which when scratched or powdered gives a cherry-red color.

IGNEOUS. A term applied to rocks that have originated in a molten condition.

JOINTS. More or less steeply inclined fractures which cross the granite sheets and which are attributed to various stresses.

KAOLIN. A hydrous silicate of alumina derived from the alteration of feldspar.

KAOLINIZATION. The process by which a feldspar passes into kaolin.

KNOTS. A term applied by quarrymen to dark gray or black objects, more or less oval or circular in cross-section, which are segregations of black mica or hornblende formed in the granite while in a molten state. English quarrymen call them "heathen."

KNOX HOLE. A circular drill hole with two opposite vertical grooves which direct the explosive power of the blast.

LEWIS HOLE. An opening made by drilling two or three holes near together and chiseling out the intervening rock.

LIMONITE. A hydrous oxide of iron ($2Fe_2O_3$, $3H_2O$); a hydrated hematite, which, when scratched or powdered, gives a brownish rust color.

MATRIX. The general mass of a rock which has isolated crystals; sometimes called groundmass.

MILLIMETER. French decimal lineal measure, the thousandth part of a meter or the tenth part of a centimeter. It is nearly equivalent to 0.04 inch, the meter being 39$\frac{1}{7}$$\frac{9}{}$ inches.

MONOLITH. A column or monument of one stone.

MOTION. A term used in granite regions to designate small paving-block quarries.

OPHITIC. A term applied to microscopic rock texture to designate a mass of longish interlacing crystals, the spaces between which have been filled with minerals of later crystallization.

OREÏ. A term applied in the Quincy quarries to granite which has been rendered valueless by the alteration of its ægirite particles.

PEGMATITE. A very coarse granite occurrring in irregular dikes or lenses in granites and some other rocks.

PLAGIOCLASE. A term applied to all those feldspars that are not potash feldspars.

PNEUMATOLYTIC. A term used by geologists to designate those minerals which are formed by superheated mineral solutions associated with the intrusion or eruption of igneous rocks.

POLARIZED LIGHT. Light whose vibrations, unlike those of ordinary light, which are in all directions, are in only one plane. Polarized light is used in the microscopic study of rocks.

PORPHYRITIC. A term applied to rock texture to designate the presence of isolated crystals in a general mass (matrix or groundmass) of finer material.

PSEUDOMORPH. Signifies false form, and designates a crystal in which, owing to various chemical changes, the original mineral has been more or less replaced by others. The form of the crystal no longer corresponds to the mineral.

QUARTZ MONZONITE. Technical designation for a granite in which the percentages of soda-lime and of potash feldspar are nearly the same or in which the former exceeds the latter. In ordinary granites the amount of soda-lime feldspar is relatively small.

RANDOM STONE. A term applied by quarrymen to quarried blocks of any dimensions. (See definition of dimension stone.)

RIFT. A quarrymen's term to designate an obscure microscopic cleavage in granite which greatly facilitates quarrying.

RUN. A term used by quarrymen in connection with "rift," apparently to denote the course of the deflection of the rift due to gravity, strain, or other not yet understood cause.

SALT-HORSE. Quarrymen's term for aplite.

SAND SEAMS. Quarry term for more or less minute veins or dikes of muscovite (white mica) with some quartz, in cases also with feldspar.

SAND STREAKS. Same as sand seams.

SAP. Quarrymen's term for ferruginous discoloration along sheet or joint surfaces.

SCHIST. A rock made up of flattish particles arranged in rough parallelism, some or all of which have crystallized under pressure.

SCHISTOSITY. The quality of being like a schist.

SEAM. Quarrymen's term for joint.

SECONDARY MINERALS. Minerals whose presence is due to the alteration of the original minerals.

SEDIMENTARY. A term designating those rocks that consist of particles deposited under water.

SEGREGATION. The scientific term for "knot;" a collection of material separated from other material. A VEIN OF SEGREGATION is one formed by the filling of a fissure with mineral matter originating in the surrounding rock.

SERICITE. A more or less fibrous form of muscovite (potash mica), often resulting from the alteration of feldspar.

SHAKES. Quarrymen's term to designate a somewhat minute close-joint structure, which forms along the sheet surface as a result of weathering (?).

SHEET QUARRY. A quarry in which the granite lies in sheets, crossed by wide-spaced steep joints.

SLICKENSIDES. The polished and grooved faces of a joint or bed caused by motion and friction.

STRAIN-SHEET. Quarrymen's term for granite sheets produced by present compressive strain.

STRATIFIED. A term applied to rock consisting of originally horizontal beds or strata.

STRIKE. The direction at right angles to the inclination of a plane of bedding, a sheet, or joint, etc.

STRIPPING. The material (sand, clay, soil, etc.) overlying a rock of economic value, which must be removed before quarrying.

SPECIFIC GRAVITY. The weight of a rock or mineral compared to that of a body of distilled water of the same bulk.

SUBJOINT. Minor joints diverging from or parallel to the regular joints.

SYNCLINE. A geological term for the trough part of a wave-like sheet or bed of rock.

TIGHTSET. Quarrymen's term, equivalent to blind seam, an incipient joint, in places associated with microscopic quartz veins.

TILL. A mixture of clay and bowlders deposited by glaciers.

TOEING-IN. Quarrymen's term for the wedging in of the end of a granite sheet under an overhanging joint, probably in consequence of the faulting of the sheets along the joint. It is also applied to the overlapping of lenticular sheets.

"TOE NAILS." Curved joints intersecting the sheet structure, in most cases striking with the sheets, in some differing from them in strike 45° or more.

TWIN CRYSTALS. Two adjacent crystals which have formed with the poles of their main axes in opposite or different directions.

WEATHERING. The decomposition of a rock owing to the action of the weather.

WHITE HORSE. Term used by quarrymen to denote a light-colored gneiss, aplite, or pegmatite.

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